APPENDIX D – POTENTIAL FOR INTERFERENCE BETWEEN IMT-2000 ENVIRONMENT AND AIR COMBAT TRAINING SYSTEMS (1755-1850 MHZ)

The 1755-1850 MHz frequency band is used by Air Combat Training Systems (ACTS) such as the Air Force's Air Combat Maneuvering Instrumentation (ACMI) and the identical Navy Tactical Air Combat Training System (TACTS). These existing ACTS systems transmit data to the aircraft on either 1830 or 1840 MHz and receive data from the aircraft on either 1778 MHz or 1788 MHz. Phase-modulated ranging tones and 198.4 kb/s data, using frequency shift keying, are transmitted. Point-to-point links in this band are also used to communicate the data from remote sites to a central location.

Current plans call for existing ACTS to be operating well past 2010. Under the current plan, the Joint Tactical Combat Training System (JTCTS) would not begin replacing existing ACTS until after 2006, with a replacement schedule into at least the 2010 time frame. The JTCTS data links operate air-to-ground, ground-to-air, and ground-to-ground, and can tune across the band 1710-1850 MHz in 5 MHz increments. The JTCTS data link signal structure is l6-ary, orthogonal signaling, with 0.351, 0.703, and 1.406 Mb/s data rates combined with either 5.63 or 22.5 Mc/s pseudorandom spreading codes.

This appendix addresses the possible interference between IMT-2000 base and mobile stations and the ACTS, also described as the TACTS/ACMI and the JTCTS operating in the frequency band 1755-1850 MHz.

D.1 OPERATIONAL MISSION OVERVIEW

The mission of the Air Force ACTS ranges, as prescribed in Air Combat Command (ACC) regulation 23-24, is to "maximize the combat readiness, capability, and survivability of participating units by providing realistic training in a combined air, ground, and electronic threat environment while providing for a free exchange of ideas between forces." Specifically, the range objectives are to force the crewmember to cope with an action-reaction sequence of threat events that (1) reflects the realities of imperfect intelligence and the limitations of operational plans, (2) yields an opportunity to practice handling larger amounts of information under stress, and (3) provides recognition that other players are influencing the scenario, the threat, and the outcome.

The ACTS supports simultaneous engagement of multiple air combat participants in state-of-the-art air-to-air, air-to-ground, ground-to-air, and electronic warfare (EW) environments. The system provides real-time monitoring and post mission reconstruction capabilities to enhance debriefing of combat aircrews. The system provides aircrew training such as aircraft handling capability, basic fighter maneuver, or intercept and air combat training sorties up to and including large composite force training.

Live air combat training is essential in order to expose pilots and combat systems operators to the complexities and stresses under which they are expected to execute their intended missions in actual combat. A key part of this training is the capability to provide accurate feedback directly to the aircrews and the probable or actual results of their actions. The required training environment and feedback capability can only be provided with special instrumentation such as ACTS and JTCTS. The time-related data, provided by this instrumentation—aircraft instantaneous position, velocity vector and accelerations, maneuvering history, and combat system activity history—forms the only possible objective information for feedback. This data supports weapons engagements performed with simulated weapons fly-outs and endgame results, instead of utilizing real weapons for obvious safety reasons and the prohibitive cost of expending actual weapons in a training situation. The ability to provide this type of support ensures each flight hour flown is maximized in terms of effectiveness and cost efficiency.

Without the training feedback from ACTS, aircrews may develop the habit of launching their air-to-air or air-to-ground weapons “out of the envelope” or not maintaining radar-lock throughout the simulated launch of a weapon. These bad habits can be deadly in air combat. Aircrews can deploy and fly in support of the combatant commanders without ACTS training, but in the words of one Air Force fighter pilot, “It’s like sending a little league baseball player straight into the big leagues. With little or no training and experience, the player will most likely strike out. In our case, we don’t strike out, we get shot down.” In addition, both the Air Force and Navy systems are used by allied nations during training in the US. This opportunity to train in coalition operations is invaluable as air operations over Kosovo showed.

In the early 1990s, the Navy began development of a system that would not only replace and upgrade their “legacy” TACTS but also provide a capability to take the TACTS function to sea with a carrier battlegroup. Subsequently, the Office of the Secretary of Defense (OSD) mandated expansion of the Navy’s Tactical Combat Training System (TCTS) program to cover Joint Air Force and Navy requirements for the next-generation ACTS. The initial focus of the Joint TCTS (JTCTS) program is on development and production of the mobile (“rangeless”) configuration, which does not impact the continental US (CONUS)-based IMT-2000 deployment. Development and production of the fixed range configuration (and replacement of all the legacy ACTS within CONUS) is not currently scheduled until the 2008-2017 time frame. While some existing “fixed” ranges may be replaced by rangeless capability, Major Training Centers (MTCs) of all services provide infrastructure that are planned to be preserved and modernized with JTCTS derived “fixed applications.”

TACTS is the primary tool at the Navy Fleet Replacement Squadron (FRS) and Marine Training Squadron level, where the aircrews first learn how to fly and fight with the specific aircraft they will operate in the Fleet. ACTS is essential to the advanced tactical training—Strike-Fighter Advanced Readiness Program (SFARP), Fighter Advanced Readiness Program (FARP), and Top Gun—that the F/A-18 and F-14 aircrews go through as their squadrons prepare for eventual carrier deployment. TACTS is critical to the ability of the Naval Strike and Air Warfare Center (NSAWC) and Marine Aviation Weapons And Tactics Squadron One (MAWTS-1) to prepare and evaluate the ability of carrier air wings and Marine aviation tactical squadrons to carry out complex coordinated combat operations. Similar Air Force schools and large air exercises like Red Flag at Nellis Range rely on ACMI systems to conduct similar training regimen.

JTCTS systems will be fielded more widely in the future to support more robust "joint" training, as the Services become more interdependent. JTCTS will fulfill the same functions as ACTS with added flexibility to support the rangeless training concept with fewer constraints than what is currently associated with the ACTS ground infrastructure.

D.2 SYSTEM DESCRIPTIONS

Technical characteristics of the TACTS/ACMI and JTCTS, together with relevant operational assumptions, are given in the following paragraphs.

D.2.1 TACTS/ACMI Characteristics

D.2.1.1 System Characteristics

Characteristics of the TACTS/ACMI system are given in Tables D-1, D-2, and D-3. Values are those in the frequency allocation applications,[1,2,3,4] unless noted otherwise. Unique radio frequency (RF) parameters of some of the Air Force ACTS ranges are not considered in this analysis. Certain parameters of the internal AIS units were not available. The values were estimated based on the corresponding parameters of the Airborne Instrumentation Subsystem (AIS) pod units, and the shaded cells of Tables D-1 and D-2 indicate these parameters. For transmitter emission bandwidths and receiver IF bandwidths, as well as harmonic and spurious levels, the DD Form 1494 values were used instead of the specified values.[5] It was felt the specified values represented a limit not to be exceeded, while the 1494 values more closely represented actual system characteristics. TACTS/ACMI frequencies and the link types associated with their use are listed in Table D-4.

D.2.1.2 Operational Considerations

In an earlier analysis for the Air Force Frequency Management Agency (AFFMA),[6] ground-to-air separation distances of 78 and 35 km were used. These values correspond to 48.5 mi (42.1 nmi) and 21.75 mi (18.9 nmi) respectively. The specified nominal maximum range appears to be 65 nmi.[7] The separation distances of 78 km (42.1 nmi) and 35 km (18.9 nmi) were used in the TACTS/ACMI portion of this analysis.[8]

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[1] Application for Equipment Frequency Allocation (DD Form 1494) for AN/TSQ-T4 Master Station and subsequent Notes to Holders, J/F 12/4321, Washington, DC: MCEB, April 1975.

[2] Application for Equipment Frequency Allocation (DD Form 1494) for AN/TSQ-T4 Remote Stations and subsequent Notes to Holders, J/F 12/4322, Washington, DC: MCEB, April 1975.

[3] Application for Equipment Frequency Allocation (DD Form 1494) for AN/TSQ-T4 Up Link and subsequent Notes to Holders, J/F 12/4323, Washington, DC: MCEB, April 1975.

[4] Application for Equipment Frequency Allocation (DD Form 1494) for TACTS, ACMI AIS Pods and subsequent Notes to Holders, J/F 12/4324/2, Washington, DC: Naval Air Systems Command, May 1987.

[5] Fred Williar, Naval Air Systems Command, e-mail to Allan Baker, IITRI, Subject: More TACTS Data, Patuxent River NAS, MD, September 27, 2000.

[6] Wayne Wamback, The Potential for Interference Between IMT-2000 Systems and US DoD Systems Operating in the Frequency Band 1755-1850 MHz, Annex 2, Alexandria, VA: AFFMA, 28 February 2000.

[7] James E. Keeler, AAC/WMRR, e-mail to J. Don Simmons, Civ AAC/WMRR, *Subject: DoD Forms for 1755 – 1850 MHz IMT-2000 Study*, September 13, 2000.

[8] Fred Williar, Naval Air Systems Command, e-mail to Allan Baker, IITRI, *Subject: TACTS AIS Data*, Patuxent River NAS, MD, September 27, 2000.

Table D-1. TACTS/ACMI Transmitter Characteristics

Transmitter Characteristic	TIS Master	TIS Remote	TIS Uplink	AIS Downlink (Pod)[a]	AIS Downlink (Internal)[d]
Power (W)	20	1 or 5[b]	5 [c]	20	10-15 (min)[e]
Modulation Type	FSK,PM	FSK,PM	FSK,PM	FSK,PM	FSK,PM
Modulation Indices	0.9,0.3,0.3	0.9,0.3,0.3	9,3,3	9,3,3	8.2,2.7,2.7
Carrier Deviation (FSK)	± 74.4 kHz	± 74.4 kHz	± 74.4 kHz	± 74.4 kHz	± 74.4 kHz
Data Rate (kb/s)	198	198	198	198	198
Widest Emission Bandwidth (MHz)					
-3 dB	0.6	0.6	3.0	2.0	3.0
-20 dB	0.8	0.8	7.0	8.0	7.0
-60 dB	2.1	2.1	12.0	12.0	12.0
Harmonic Attenuation (dB)	70	70	70	85	85
Spurious Attenuation (dB)	70	70	70	70	70

[a]The calibration transponder at the master station is electronically identical to the AIS pod.
[b]Depends on manufacturer. Cubic Corp. uses 1 W, ADT uses 5 W (Ref. 5).
[c]20 W at Tyndall ACMI and Yukon MDS ranges (Ref. 5).
[d]Data consolidated from Ref. 8.
[e]15 W applies to AISI(K) (Ref. 8).

Table D-2. TACTS/ACMI Receiver Characteristics

Receiver Characteristic	TIS Master	TIS Remote	TIS Downlink	AIS[a] (Pod)	AIS (Internal)[d]
Sensitivity (dBm)	-95 (BER = $1x10^{-5}$)	-95 (BER = $1x10^{-5}$)	-95 (BER = $1x10^{-5}$)	-99 (10 dB S/N) (BER = $1x10^{-5}$)	-95 dBm (100% response), -99 dBm (50% response)
Noise Level[e] (dBm)	-110	-110	-110	-111	-111
IF Bandwidth[b] (MHz)					
-3 dB	1.5	1.5	1.5	1.2	1.2
-20 dB	5.0	5.0	5.0	3.0	3.0
-60 dB	12.0	12.0	12.0	8.0	8.0
Receiver Selectivity[c] (MHz)					
-3 dB	1.5	1.5	1.5	1.2	1.2
-20 dB	2.9	2.9	2.9	3.0	3.0
-60 dB	7.4	7.4	7.4	6.8	6.8
Spurious Response (dB)	60	60	85	85	85

[a]The calibration transponder at the master station is electronically identical to the AIS pod.
[b]Second IF bandwidth
[c]Bandwidth of combined first and second IF stages.
[d]Data consolidated from Ref. 8.
[e]Calculated using 2.7 dB noise figure, from Ref. 5.

Table D-3. TACTS/ACMI Antenna Characteristics

Antenna Characteristic	TIS Master	TIS Remote	TIS Uplink/ Downlink	AIS (Pod)	AIS (Internal)
Type	Parabolic (Dipole Arrays)/ Broad Beamwidth	Parabolic	Crossed Dipole Array	Dipole	Dipole
Gain (dBi)	28,24, 20[d]/14.5	26	3.0	0	0
Polarization	V & H	V,H	RHCP	RHCP	RHCP
Height (ft)	75 (300 max)[e]	100-150	160 (100-150)[e]	30,000[a,c]	55,000-60,000[a,b]

[a]Maximum altitude above mean sea level
[b]From Reference 8.
[c]Reference 5 gives a range of 10,000 to 30,000 ft. This reference also states that the tracking instrumentation subsystem (TIS) is specified to track aircraft within altitudes of 500 ft. to 40,000 ft above the range floor.
[d]Different values are given. The 20-dB value is given in Reference 1. Although a broad beamwidth is usually desired, the antenna gain may depend on the installation.
[e]Antenna height is site-dependent.

Table D-4. TACTS/ACMI Frequencies and Usage

Type of Link	Frequencies (MHz)
Master-to-Remote	1768 or 1769
AIS-to-Remote (Downlink)	1788 “A” Pod or 1778 “B” Pod
Remote-to-Master	1797, 1802, 1807, 1812, 1817, 1822
Remote-to-AIS (Uplink)	1840 “A” Pod or 1830 “B” Pod

The maximum number of aircraft is stated to be 36 (Reference 7). For the Nellis ACTS and the Alaska Upgrade (AAU), as many as 100 aircraft can be supported. In this analysis, the effect of the number of aircraft flying at a given time was not considered.

Altitudes of 5000 m (16,400 ft) and 9000 m (29,530 ft) were used in Reference 6. A somewhat higher maximum altitude of 40,000 feet above range floor is given in Reference 5, and altitudes of 55,000 to 60,000 feet are given for the internal AIS equipment (Reference 8). The 9000 m (approximately 30,000 ft) altitude was used in this analysis.

A representative sample of TACTS and ACMI training center sites is shown in Figure D-1.

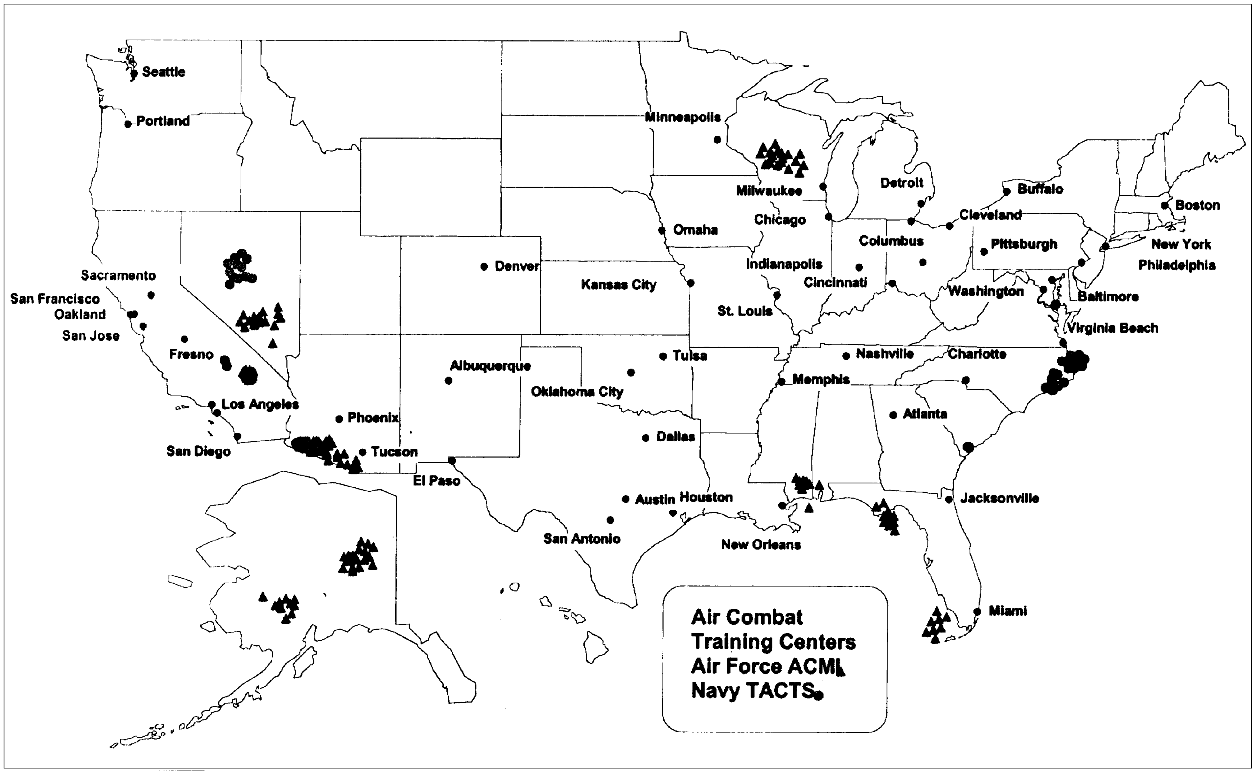

Figure D-1. Representative Sample of Air Combat Training Center Sites

D.2.2 JTCTS Characteristics

D.2.2.1 System Characteristics

Tables D-5, D-6, and D-7 contain characteristics of the JTCTS. Characteristics were obtained from the frequency allocation application,[9] SRI International reports[10,11] and material from the system manufacturer which was provided by SRI International.[12,13] The high-power mode of operation (67.6 W) was assumed. The shaded boxes contain assumed values.

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[9] Application for Equipment Frequency Allocation (DD Form 1494) for Joint Tactical Combat Training System (JTCTS) Instrumentation Data Network, (Stage 4), J/F 12/06999/2, Patuxent River, MD, NAWCAD, 10 July 1998.

[10] David Hanz, Results from Phase 1a of the GSM-1800/JTCTS Datalink Signal Compatibility Test Program, Special Report 10240-99-SR-110, Menlo Park, CA: SRI International, November 1999.

[11] US DoD Air Combat Training Systems Development Roadmap for Next Generation & Spectrum Compatibility Issues, dated 12 January 2000. Briefing given by D. Hanz of SRI International, 11 September 2000.

[12] Raytheon Systems Company, *JTCTS Data Link Overview*, Slide Package, undated, attachment to D. Hanz, SRI International, e-mail to A. Baker, IITRI/JSC, September 25, 2000. *Subject: Reference Material #1.*

[13] Dave Hanz, SRI International, e-mail to Allan Baker, IITRI, *Subject: More Reference*, 25 September 2000, with attachment Raytheon Specification G644379 8 February 1996 CAGE Code 49956 Rev. A: 31 December 1996.

Table D-5. JTCTS Transmitter Characteristics

Transmitter Characteristic	Narrowband	Wideband
Power (W)	7.6 or 67.6	7.6 or 67.6
Tuning	Frequencies are selectable from 1710-1850 MHz in 5-MHz increments (1755-1850 MHz in US&P).	
Modulation Type	OQPSK with DS spread spectrum, 16-ary orthogonal Walsh signaling	
Data Rate (kb/s)	351.5625, 703.125, 1406.25	351.5625, 703.125, 1406.25
Chip Rate (Mc/s)	5.63	22.5
Protocol	TDMA-100 ms frame, Primary IDN: 25 slots/frame Secondary IDN: 10 slots/frame	
Error Detection and Correction	Reed-Solomon FEC Short Data Slots: (116,100) Long Data Slots: (128,100) Relay Slots: (56,40)	
Emission Bandwidth (MHz)		
-3 dB	2.1	4.8
-20 dB	5.63	22.5
-60 dB	22.5	90
Harmonic Attenuation (dB)		
(2 & 3)	70	70
Other	80	80
Spurious Attenuation (dB)	80	80

Table D-6. JTCTS Receiver Characteristics

Receiver Characteristic		
Sensitivity (dBm)	-106.5 @ 14.1 dB E_b/N_o, 351.56 kb/s, RS coding	
Noise Figure (dB)	4.5	
Receiver Noise Level, dBm[b]	-114.0 (352.6 kb/s), -111.0 (703 kb/s), -108 dBm (1406 kb/s)	
First IF Bandwidth (MHz)	Narrowband[c]	Wideband
-3 dB	22.5	22.5
-20 dB	45	45
-60 dB	60	60
Implementation Losses (dB)	2	
Spurious Response (dB)	60	
Image Rejection (dB)	100	
Intermediate Frequency (MHz)	400	
[a]It is expected that additional selectivity is present, at the second IF or baseband [b]In bandwidth equal to the bit rate. [c]No additional filtering is used for the narrowband mode.[14]		

[14] David Hanz, SRI International, e-mail to Allan Baker, IITRI/JSC, 9 October 2000, Subject: JTCTS Characteristics.

Table D-7. JTCTS Antenna Characteristics

Antenna Characteristic	Instrumentation Data Link (Aircraft Fuselage Mounted)	Instrumentation Data Link (Aircraft Pod Mounted)	Ship-to-Shore Link
Type	¼ λ monopole blade	½ λ crossed dipoles	Stacked dipole array
Gain (dBi)	2	6	8
Polarization	V	H,V	V
Height (ft)	30,000	30,000	

D.2.2.1.2 Operational Considerations

In Reference 6, ground-to-air separation distances of 78 and 35 km were used for both the TACTS/ACMI and JTCTS analyses. These values correspond to 48.5 mi (42.1 nmi) and 21.75 mi (18.9 nmi) respectively. However, it is realized that for the JTCTS, the ground-to-air links are secondary and tertiary links. The primary link is the air-to-air link, with a maximum distance of 150 nmi (278 km). A separation distance of this magnitude plus a smaller one (78 km or approximately 50 mi) were used in the analysis.

The maximum number of aircraft is stated to be 100 for JTCTS, according to discussions at a 25 September 2000 meeting with Naval Air Systems Command (NAVAIR) and SRI International personnel and to Reference 7. Typical numbers of aircraft may be somewhat less. In this analysis, the effect of the number of aircraft flying at a particular time was not considered.

Altitudes of 5000 m (16,400 ft) and 9000 m (29,530 ft) were used in Reference 6. Some of the material provided for the TACTS system indicates that maximum altitudes may be higher (e.g., 40,000 to 60,000 feet). However, after coordination with JTCTS engineering and operational personnel, an altitude of 9000 m (approximately 30,000 ft) was used in both the TACTS/ACMI and JTCTS parts of the analysis.

D.3 COST ISSUES

D.3.1 Aircraft Combat Training Systems

The DoD is developing the next generation air combat training system to replace the existing ACTS equipment. This system, called the Joint Tactical Combat Training System (JTCTS), is a Global Positioning System (GPS)-based system. JTCTS, as designed, utilizes the 1755-1850 MHz band. However, JTCTS can be retuned to a segment of the 1755-1850 MHz band or relocated to another band of comparable spectrum, given one's availability. This is the key assumption regarding DoD proposed mitigation approach for tactical aircraft training systems under the full-band loss option. If a comparable band in S-band is not made available a much more expensive, complicated, and yet to be defined alternative, will be required.

The proposed DoD mitigation plan for ACTS is to retune to the segmented band or relocate to an alternate JTCTS band, accelerate immediately the development work necessary to reconfigure JTCTS equipment to the operating band, and then to accelerate to the extent possible fielding of the system considering the large number of aircraft affected and the number of ranges that utilize TACTS/ACMI equipment. The acceleration can be large, as in the 2006 IMT-2000 build-out case, or more gradual in the 2010 case. Given the current JTCTS program, relocating and fielding JTCTS for all legacy ACTS in 2006 is high risk (questionable feasibility) or in 2010 is medium to high risk even with immediate funding. Table D-8 shows the cost impact of relocating JTCTS under the 2010 option assuming total band loss to DoD.

Table D-8. Joint Tactical Combat Training System (JTCTS) (TY$M)

	FY02	FY03	FY04	FY05	FY06	FY07	To Complete	Total
JTCTS Acceleration	15.2	55.7	44.8	68.6	48.6	34.8	173.0	440.7

D.4 OPTION 1 – FULL BAND SHARING

D.4.1 TACTS/ACMI Technical Assessment

D.4.1.1 Interference from IMT-2000 into TACTS/ACMI Airborne Receivers

The calculation of aggregate IMT-2000 interference into the TACTS/ACMI and JTCTS airborne receivers was done in a manner similar to that in Reference 6, which was based on the levels used in Recommendation ITU-R M.687-2.[15] Two training ranges were selected, Cherry Point Marine Corps Air Station (MCAS), in the eastern US, and Nellis Air Force Base (AFB) in the western US. Both training ranges were within LOS of at least one major metropolitan area. For each training range, a point within the boundary of the flight area was selected, and metropolitan areas within the radio line of sight (LOS) of this point were selected. The assumed aircraft receiver altitude was 9000 m (approximately 30,000 ft). For each city, the equivalent area was calculated, and the propagation loss was calculated using the

[15] International Telecommunication Union, International Mobile Telecommunications-2000 (IMT-2000), Recommendation ITU-R M.687-2, 1997.

JSC Spherical Earth Model (SEM)[16] with the modified free space option. Antenna heights used were 40 m for the IMT-2000 base stations and 9000 m for the airborne receiver. For these antenna heights and an assumed smooth earth, the radio LOS was calculated to be approximately 260 miles.

The total power at the airborne receiver was calculated using Equation D-1 (Adapted from Reference 6):

$$I(\text{dBW/Hz}) = \sum_{i=1}^{n} P_d\, P_{mi}\, D_{pl}\, l_{pi} \qquad \text{(D-1)}$$

where:

- P_d = power density per square kilometer per Hertz generated by IMT-2000 stations in an urban environment. Given by Reference 15 as 38 μW/km^2/Hz
- P_{mi} = population of the ith visible metropolitan area, in millions
- D_{pl} = average inverse population density, in km^2 per million
- l_{pi} = path loss from the ith metropolitan area, equal to $10^{-L/10}$, where L is the path loss from the JSC SEM, in dB

Values of P_m used were the populations of the Ranally Metropolitan Areas, taken from the Rand McNally Commercial Atlas and Marketing Guide.[17] The values used are population estimates for 1 January 1999.

In Reference 6, the average population density was determined by averaging the population densities of the metropolitan areas or central cities for eight world cities. The average ratio was calculated to be 144.2 km^2/million.

As in Reference 6, a factor for environmental losses, 10 dB, was subtracted from the results of Equation D-1. Use of a lesser value, such as 0 dB, was also considered.

The results of the calculations using Equation D-1 are given in Tables D-9 and D-10 for Nellis AFB and Cherry Point, respectively.

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16 David Eppink and Wolf Kuebler, *TIREM/SEM Handbook*, ECAC-HDBK-93-076, Annapolis, MD: DoD ECAC, March 1994.

17 Rand McNally & Co., *Rand McNally 2000 Commercial Atlas & Marketing Guide*, 131st Edition, 2000, pp. 124-125.

Table D-9. Power Levels from Nearby Cities, Nellis AFB ACMI Range

City	Distance		Population (Metro Area) (mil.)	Equiv. Area (km^2)	Path Loss, dB	Received Power Density (dBW/Hz)
	Miles	km				
Las Vegas, NV	58	93	1.2575	181.3	137	-158.6
Los Angeles, CA	260	418.4	13.11	1890.5	169.7	-181.1
Bakers-field, CA	234	376.6	0.404	58.24	149.1	-175.6
Fresno, CA	253	407.1	0.726	104.7	159.7	-183.7
Riverside, CA	234	376.6	1.536	221.5	149.1	-169.8

The total power density is -158.2 dBW/Hz; with a 10-dB factor for environmental losses, it is -168.2 dBW/Hz.

Table D-10. Power Levels from Nearby Cities, Cherry Point MCAS

City	Distance		Population (Metro Area) (mil.)	Equiv. Area (km^2)	Path Loss, dB	Received Power Density (dBW/Hz)
	Miles	km				
Richmond, VA	200	322	.861	124.1	147.7	-171.0
Norfolk, VA	140	225	1.006	144.9	144.6	-167.2
Newport News, VA	140	225	0.476	68.6	144.6	-170.4
Fayetteville, NC	135	217	0.319	46.1	144.3	-171.9
Charlotte, NC	240	386	1.215	175.3	149.3	-171.1
Charleston, SC	240	386	0.4782	69.1	149.3	-175.1
Columbia, SC	260	418	0.4924	71.0	169.4	-195.1
Raleigh, NC	140	225	0.6733	97.1	144.6	-168.9
Durham, NC	140	225	0.3273	47.2	144.6	-172.1

The total power was calculated to be -161.4 dBW/Hz; with a 10-dB factor for environmental losses, it is -171.4 dBW/Hz.

Results of the interference calculations are given in Table D-11 for TACTS/ACMI air-to-ground separation distances of 35 and 78 km, for the aggregate interfering signal without environmental losses, the interfering signal with 10 dB losses, and the interfering signal attenuated by 10 dB, with the 10 dB loss factor. The 10-dB attenuation may approximate a situation where the IMT-2000 system is near the beginning of its full-scale implementation.

The results in Table D-11 show that the TACTS/ACMI link margins are degraded to -22 to -29 dB, with the full aggregate interfering signal, with 10 dB of environmental losses. With 10 dB less interfering power than predicted with the full operational implementation, link margins are still degraded to -12 dB at the 35 km TACTS/ACMI transmitter-to-receiver separation distance and -19 dB at the 78-km separation distance. Since a number of factors could cause the calculated numbers to be higher than those shown, the results suggest that sharing in a full IMT-2000 environment is not feasible.

Table D-11. TACTS/ACMI Airborne Receiver Link Margins With and Without IMT-2000 Interference

Aircraft Altitude	9000 m	9000 m
Distance from Ground Transmitter	78 km	35 km
Range Between A/C and Ground Transmitter	78.52 km	36.14 km
Ground Transmitter Power	7 dBW	7 dBW
Transmit Antenna Gain	0 dBi	0 dBi
Transmitter System Losses	2 dB	2 dB
Transmitter Data Rate (198.4 kb/s)	53.0 dB/Hz	53.0 dB/Hz
Transmit E_b	-48 dBW	-48 dBW
Free Space Path Loss (1800 MHz)	135.4 dB	128.7 dB
Airborne Receiver Antenna Gain	0 dBi	0 dBi
Rx Noise (3 dB NF)	-201 dBW/Hz	-201 dBW/Hz
E_b/N_o	17.6 dB	24.3 dB
Criterion (E_b/N_o for BER = 10^{-5})	13.35 dB	13.35 dB
Margin (No Interference)	4.2 dB	10.9 dB
I_o	-158 dBW/Hz	-158 dBW/Hz
$E_b/(N_o + I_o)$	-25.4 dB	-18.7 dB
Degraded Below Criterion	38.8 dB	32.1 dB
I_o	-168 dBW/Hz	-168 dBW/Hz
$E_b/(N_o + I_o)$	-15.4 dB	-8.7 dB
Degraded Below Criterion	28.8 dB	22.1 dB
I_o	-178 dBW/Hz	-178 dBW/Hz
$E_b/(N_o + I_o)$	-5.4 dB	1.3 dB
Degraded Below Criterion	18.8 dB	12.1 dB
I_o	-188 dBW/Hz	-188 dBW/Hz
$E_b/(N_o + I_o)$	4.6 dB	11.3
Degraded Below Criterion	8.8 dB	2.1 dB

D.4.1.2 Interference from IMT-2000 into TACTS/ACMI Ground-Based Receivers

To analyze interference from IMT-2000 into TACTS/ACMI ground-based receivers, the required separation distance to preclude interference into a ground receiver from a single IMT-2000 base and mobile transmitter was calculated. The IMT-2000 parameters used in the calculations are given in Tables A-4 and A-5. The TACTS/ACMI ground receiver and antenna parameters are given in Tables D-1, D-2, and D-3.

As was assumed in Reference 6, TACTS/ACMI operations are link-margin limited. The volume of space usable for flight training is determined by the available link margin. It was assumed that the maximum range between ground-based and airborne equipment, which determines the maximum aircraft-to-aircraft separation, cannot be reduced by more than ten percent due to interference from IMT-2000 systems. This condition equates to an allowed degradation in the TACTS/ACMI link margin of approximately 1 dB and an I/N of –6 dB. It is noted, as in Reference 6, that the full amount of interference degradation is made available to IMT-2000, rather than only ten percent of the total interference budget, as is often considered reasonable.

Interference between ground-based transmitters and receivers was calculated using Equation D-2:

$$I = P_T + G_T + G_R - L_P - L_S - L_{SP} - FDR \qquad \text{(D-2)}$$

where

I	=	interference power in receiver, in dBm
P_T	=	transmitter power, in dBm
G_T	=	transmitter antenna gain in direction of receiver, in dBi
G_R	=	receiver antenna gain in direction of transmitter, in dBi
L_P	=	propagation loss, in dB
L_S	=	system losses, in dB
L_{SP}	=	processing loss of interference in a spread spectrum receiver, in dB
FDR	=	frequency-dependent rejection, in dB.

The interference power I was set to a maximum allowable value, the interference threshold I_t, which is set for the TACTS/ACMI receivers at 6 dB below the receiver noise level, and Equation D-2 was rearranged to form Equation D-3:

$$L_P = P_T + G_T + G_R - L_S - L_{SP} - FDR - I_t \qquad \text{(D-3)}$$

where quantities are as previously defined.

The factor L_{SP}, for a direct-sequence spread spectrum receiver such as those used for CDMA versions of the IMT-2000, is given by Equation D-4:

$$L_{SP} = 10 \log (R_c/R_d) \qquad \text{(D-4)}$$

where:

R_c	=	chip rate of receiver, chips/s
R_d	=	data rate of system, bits/s.

Frequency-dependent rejection (FDR) for the ontune cases considered here is given by Equation D-5:

$$\mathrm{FDR} = 10 \log (B_t/B_r) \quad \text{for } B_t > B_r$$
$$0 \quad \text{for } B_t \le B_r \qquad \text{(D-5)}$$

where:

B_t = transmitter 3-dB emission bandwidth, in Hertz

B_r = receiver bandwidth, in Hertz.

The receiver bandwidth for use in Equation D-5 was assumed equal to the chip rate, for code division multiple access (CDMA) IMT-2000 receivers and other direct-sequence spread-spectrum receivers. For time division multiple access (TDMA) receivers, the receiver bandwidth and bit rate were assumed equal for this analysis, at 30 kHz for the IS-136 and 176 kHz for the Groupe Speciale Mobile (GSM) system, and the L_{SP} term is not applicable.

The required separation distance to preclude interference was calculated using the required propagation loss from Equation D-3 and the JSC Inverse Smooth Earth Model. Antenna heights used were 40 m and 1.5 m for the IMT-2000 base station and mobile transmitters respectively, and 30 m for the TACTS/ACMI receivers. The required separation distances are given in Table D-12. The distances shown are the maximum for all versions of the IMT-2000 listed in Tables A-4 and A-5. For one case, the wideband CDMA, a FDR of 3 dB would lower the separation distances slightly. For the other three IMT-2000 versions, the FDR is 0 dB. TACTS/ACMI antenna gain values of 26 dBi and 0 dBi were used. The 26 dBi gain represents either the master or the remote station in a ground-to-ground interaction. The 0-dBi gain represents the remote station used as a TIS uplink. It is expected that the 3-dBi gain shown in Table D-3 would be reduced by 3 dB for polarization differences between the right-hand circular polarization of the TACTS/ACMI antenna and the linear polarization of the interfering signal.

Table D-12. Distances, in km, from IMT-2000 Transmitters to Preclude Interference to TACTS/ACMI Ground-Based Receivers

TACTS/ACMI Antenna Gain (dBi)	IMT-2000 Station	
	Mobile	Base
0	20.0	70.1
26	38.9	146.1

D.4.1.3 Interference from TACTS/ACMI Ground-Based Transmitters into IMT-2000 System

Separation distances to be maintained by IMT-2000 receivers from TACTS/ACMI ground transmitters to preclude interference were calculated using the path loss from Equation D-3 and the inverse SEM propagation model. Parameters for the IMT-2000 receivers are taken from Tables A-4 and A-5 and parameters for the TACTS/ACMI transmitters and antennas were taken from Tables D-1 and D-3. For the IMT-2000 receiver interference criteria, the two values in Tables A-4 and A-5 were used, plus an additional, higher value, corresponding to the desired signal 20 dB above the receiver sensitivity level. It was felt that the two higher thresholds used would represent a range of realistic received signal levels. Separation distances for each interference threshold and TACTS/ACMI transmitter-antenna combination are given in Table D-13. For the highest interference threshold, only one value, the worst-case, was calculated. Distances for the other IMT-2000 versions are expected to be slightly less, as was the case for the lower thresholds.

For the narrowband TACTS/ACMI signals, the Master Station (MS) and TIS ground-to-ground links, the separation distances for the CDMA WB and NB IMT-2000 implementations are slightly smaller than for the TDMA implementation. This is because the CDMA implementations offer some processing loss to the narrowband TACTS/ACMI signal, due to the correlation of the desired signal and subsequent narrowband filtering in the receiver. The separation distances for both TDMA implementations were practically identical.

Table D-13. Distances, in km, from TACTS/ACMI Ground-Based Transmitters to Preclude Interference to IMT-2000 Receivers

TACTS/ACMI Antenna Gain and Tx Power	IMT-2000 Station					
	Mobile			Base		
	CDMA WB	CDMA NB	TDMA	CDMA WB	CDMA NB	TDMA
IMT-2000 Interference Criterion I/N = -6 dB						
MS 26 dBi/20 W	46	48.4	50.7	132.1	157.9	180.3
TIS 26 dBi/1 W	38.5	41.3	43.2	85.1	98.4	110
G/A 0 dBi/5 W	25.2	25.9	26	63.2	63.9	64
IMT-2000 Interference Criterion for S = Sensitivity + 10 dB						
MS 26 dBi/20 W	36.9	39.8	41.8	80	90.8	101
TIS 26 dBi/1 W	27.9	31.4	33.7	66	69.7	72.5
G/A 0 dBi/5 W	11.9	12.7	12.8	49.2	50.1	50.2
IMT-2000 Interference Criterion for S = Sensitivity + 20 dB						
MS 26 dBi/20 W			35.3			74.6
TIS 26 dBi/1 W			26.0			64.3
G/A 0 dBi/5 W			5.7			39.1

D.4.1.4 Interference from TACTS/ACMI Airborne Transmitters into IMT-2000 System

The required separation distances between an airborne TACTS/ACMI transmitter (at 9000 m altitude) and IMT-2000 base and mobile stations were calculated in a manner similar to those for the ground-based ACTS transmitters. For each value of required path loss, the JSC inverse smooth-earth propagation model was used to calculate the required separation distance. For the IMT-2000 base stations, a 2.5-degree downtilt angle was assumed and a maximum antenna gain, at the horizon or above, of 5 dBi was used in the analysis. Results of the calculations are shown in Table D-14. Because of the relatively wide bandwidth of the AIS downlink signal, little processing gain is realized by the CDMA implementations, and the separation distances for the three versions are not significantly different. The required separation distances for the base stations approach LOS for the lowest interference threshold, and they are in the neighborhood of 180 km for the middle interference threshold. These distances could significantly reduce the area of IMT-2000 usage near TACTS/ACMI training ranges.

Table D-14. Required Separation Distances, in km, to Preclude Interference from TACTS/ACMI Airborne Transmitters into IMT-2000 Receivers

IMT-2000 Station					
Mobile			Base		
CDMA WB	CDMA NB	TDMA	CDMA WB	CDMA NB	TDMA
IMT-2000 Interference Criterion I/N = -6 dB					
318.9	320.1	322.7	404.4	405.4	405.5
IMT-2000 Interference Criterion for S = Sensitivity + 10 dB					
57.1	63.5	64.3	162.8	180.6	182.7
IMT-2000 Interference Criterion for S = Sensitivity + 20 dB					
14.7	16.9	17.1	47.8	53.2	53.9

D.4.2 JTCTS Technical Assessment

D.4.2.1 Interference from IMT-2000 into JTCTS Airborne Receivers

The JTCTS data link signal structure is 16-ary, orthogonal signaling, with 0.351, 0.703, and 1.406 Mb/s data rates combined with either 5.63 or 22.5 Mc/s pseudorandom spreading codes. Symbol rates are 89.9, 175.8, and 351.5 kb/s. The required E_s/N_o, including Reed-Solomon forward error-correcting code gain, is 11.0 dB.

Table D-15 contains the calculations of the JTCTS link margins for the aircraft altitude of 9000 m (approximately 30,000 feet), and two separation distances, in the absence of interference. The first separation distance, 78 km, is the same as used in the TACTS/ACMI analysis. The second distance, 150 nmi (277.8 km) represents the specified maximum separation distance for the JTCTS air-to-air link

(Reference 12), which is its primary communications link. In the absence of interference, link margins vary, depending on the symbol rate, from 16 to 22 dB for the 78-km distance, and from 5 to 11 dB for the 278-km distance.

It was assumed that the JTCTS was subjected to the same aggregate IMT-2000 interference levels as those calculated earlier for the TACTS/ACMI systems. Table D-16 shows the received $Es/(N_o + I_o)$ and resulting link margins in the presence of the aggregate IMT-2000 RF environment. With I_o = -168 dBW/Hz, negative link margins of from –10 to –16 dB result, depending on the data rate, for the 78 km distance. For the 150 nmi (278 km) separation, the link margins are 11 dB less, from –21 to –27 dB. For a 10-dB lower aggregate interference level, expected to occur before a mature usage rate is developed, negative link margins exist for all but the lowest symbol rate (87.9 ksps) at the 78 km separation, and at all symbol rates at the 278 km separation.

Comparison of the results for the JTCTS and TACTS/ACMI systems show that the JTCTS link margins are somewhat higher in the presence of interference, than are those of the TACTS/ACMI. However, the effect is still such that, even with an incomplete buildup of the IMT-2000 environment, operation of the systems at typical training ranges will be degraded.

Table D-15. JTCTS Airborne Receiver Link Margins Without IMT-2000 Interference

Aircraft Altitude	9000 m	9000 m
Distance from Tx	78 km	277.8 km (150 nmi)
Transmitter Power	18.3 dBW	18.3 dBW
Transmit Antenna Gain	2 dBi	2 dBi
Tx System Losses	2 dB	2 dB
Transmit Symbol Rate		
87.9 ksps	49.5 dBHz	49.5 dBHz
175.8 ksps	52.5 dBHz	52.5 dBHz
351.6 ksps	55.5 dBHz	55.5 dBHz
Transmit Energy per Symbol		
87.9 ksps	-31.2 dBW	-31.2 dBW
175.8 ksps	-34.2 dBW	-34.2 dBW
351.6 ksps	-37.2 dBW	-37.2 dBW
Free Space Path Loss (1800 MHz)	135.4 dB	146.4 dB
Airborne Receiver Antenna Gain	2 dBi	2 dBi
Received E_s		
87.9 ksps	-164.6 dBW	-175.6 dBW
175.8 ksps	-167.6 dBW	-178.6 dBW
351.6 ksps	-170.6 dBW	-181.6 dBW
Rx N_o (4.5 dB NF)	-199.5 dBW/Hz	-199.5 dBW/Hz
E_s/N_o		
87.9 ksps	34.9	23.9
175.8 ksps	31.9	20.0
351.6 ksps	28.9	17.9
Implementation Losses	2.0 dB	2.0 dB
Required E_s/N_o	11.0 dB	11.0 dB
Margin		
87.9 ksps	21.9 dB	10.9 dB
175.8 ksps	18.9 dB	7.9 dB
351.6 ksps	15.9 dB	4.9 dB

Table D-16. JTCTS Airborne Receiver Link Margins and Degradation Due to IMT-2000

Aircraft Altitude	9000 m	9000 m
Distance from Transmitter	78 km	277.8 km
Received E_s/N_o		
87.9 ksps	-164.6 dB	-175.6 dB
175.8 ksps	-167.6 dB	-178.6 dB
351.6 ksps	-170.6 dB	-181.6 dB
I_o	-158 dBW/Hz	-158 dBW/Hz
$E_s/(N_o + I_o)$		
87.9 ksps	-6.6 dB	-17.6 dB
175.8 ksps	-9.6 dB	-20.6 dB
351.6 ksps	-12.6 dB	-23.6 dB
Margin		
87.9 ksps	-19.6 dB	-30.6 dB
175.8 ksps	-22.6 dB	-33.6 dB
351.6 ksps	-25.6 dB	-36.6 dB
I_o	-168 dBW/Hz	-168 dBW/Hz
$E_s/(N_o + I_o)$		
87.9 ksps	3.4 dB	-7.6 dB
175.8 ksps	0.4 dB	-10.6 dB
351.6 ksps	-2.6 dB	-13.6 dB
Margin		
87.9 ksps	-9.6 dB	-20.6 dB
175.8 ksps	-12.6 dB	-23.6 dB
351.6 ksps	-15.6 dB	-26.6 dB
I_o	-178 dBW/Hz	-178 dBW/Hz
$E_s/(N_o + I_o)$		
87.9 ksps	13.4 dB	2.4 dB
175.8 ksps	10.4 dB	-0.6 dB
351.6 ksps	7.4 dB	-3.6 dB
Margin		
87.9 ksps	0.4 dB	-10.6 dB
175.8 ksps	-2.6 dB	-13.6 dB
351.6 ksps	-5.6 dB	-16.6 dB
I_o	-188 dBW/Hz	-188 dBW/Hz
$E_s/(N_o + I_o)$		
87.9 ksps	23.4 dB	12.4 dB
175.8 ksps	20.4 dB	9.4 dB
351.6 ksps	17.4 dB	6.4 dB
Margin		
87.9 ksps	10.4 dB	-0.6dB
175.8 ksps	7.4 dB	-3.6 dB
351.6 ksps	4.4 dB	-6.6 dB

D.4.2.2 Interference from IMT-2000 into JTCTS Ground-Based Receivers

As was done for the TACTS/ACMI, it was assumed for the JTCTS that the maximum range between ground and air stations (which in turn determines the maximum aircraft-to-aircraft separation) cannot be reduced by more than about 10 percent due to interference from IMT-2000 systems. This condition equates to an allowed degradation in the JTCTS link margin of approximately 1 dB and an interference-to-noise power ratio criterion of –6 dB. It again is noted that the full amount of interference degradation is made available to IMT-2000, rather than apportioning only 10 percent of the total interference budget to this system, as is sometimes considered reasonable. Although a high (26 dBi) antenna gain was not given in the JTCTS system description, it was assumed that an antenna of this type could be used in a tertiary, or ground-to-ground, link.

All IMT-2000 transmitters considered were narrower in bandwidth than the narrower-bandwidth JTCTS chip rate. A processing loss equal to the ratio of the chip rate to the data rate was applied to the interfering signal level, as described earlier. For each chip rate, the separation was the same for each data rate considered. This is due to the processing loss compensating for the change in noise level. The processing loss is proportional to the data rate, while the noise power, and hence the interference threshold, is inversely proportional to the data rate. See Table D-17.

Table D-17. Separation Distances, in km, from JTCTS Ground Receivers to Preclude Interference from IMT-2000 Transmitters

JTCTS Antenna Gain, (dBi)	JTCTS Receiver Chip Rate (MChips/s)	Data Rate, Mb/s	IMT-2000 Station	
			Mobile	Base
0	5.63	0.3516	13.0	65.4
		1.406	13.0	65.4
	22.5	0.3516	8.1	58.7
		1.406	8.1	58.7
26	5.63	0.3516	33.8	117.3
		1.406	33.8	117.3
	22.5	0.3516	29.6	89.5
		1.406	29.6	89.5

D.4.2.3 Interference from JTCTS Ground-Based Transmitters into IMT-2000 System

Separation distances which may need to be maintained by IMT-2000 receivers to preclude interference from JTCTS ground transmitters were calculated in a manner similar to those corresponding distances for the TACTS/ACMI ground transmitters. The JSC inverse SEM propagation model was used, with the JTCTS characteristics of Tables D-5 and D-7 and the IMT-2000 characteristics of Tables A-4 and

A-5. Separation distances were calculated for both the narrowband and wideband JTCTS signal, and each of the four IMT-2000 variations considered, for both mobile and base stations. Results are given in Tables D-18 and D-19. In Table D-18, the separation distances for each version of the IMT-2000, against the wideband JTCTS signal, were the same. In Table D-19, the wideband CDMA version gave slightly more processing loss to the narrowband JTCTS signal, resulting in slightly smaller separation distances, when compared to the other versions, whose separation distances were identical.

Table D-18. Distances, in km, from JTCTS Wideband Ground-Based Transmitters to Preclude Interference to IMT-2000 Receivers

JTCTS Antenna Gain (dBi)	IMT-2000 Station	
	Mobile	Base
IMT-2000 Interference Criterion I/N = -6 dB		
0	32.1	71.3
12	40.3	93.4
26	48.1	154.2
IMT-2000 Interference Criterion for S = Sensitivity + 10 dB		
0	20.8	58.6
12	30.2	68.5
26	39.5	89.2
IMT-2000 Interference Criterion for S = Sensitivity + 20 dB		
0	11.7	48.9
12	22.1	60.0
26	32.8	71.4

Table D-19. Distances, in km, from JTCTS Narrowband Ground-Based Transmitters to Preclude Interference to IMT-2000 Receivers

JTCTS Antenna Gain (dBi)	IMT-2000 Station			
	Mobile		Base	
	WB CDMA	Others	WB CDMA	Others
IMT-2000 Interference Criterion I/N = -6 dB				
0	33.5	35.2	72.3	74.4
12	41.1	42.5	97.1	105.7
26	48.7	50.6	161.7	178.8
IMT-2000 Interference Criterion for S = Sensitivity + 10 dB				
0	21.8	23.9	59.6	61.8
12	31.1	32.8	69.4	71.5
26	40.2	41.7	92.5	100.4
IMT-2000 Interference Criterion for S = Sensitivity + 20 dB				
0	12.6	14.8	50.0	52.4
12	23.1	25.1	60.9	63.0
26	33.5	35.2	72.3	74.4

D.4.2.4 Interference from JTCTS Airborne Transmitters into IMT-2000 System

The interference from airborne JTCTS transmitters into IMT-2000 receivers was calculated using the same approach and path loss model as was done in a preceding section for the TACTS/ACMI system. As in the preceding section, results are given for both narrowband and wideband JTCTS waveforms. Results are given in Tables D-20 and D-21. Again, for the wideband JTCTS waveform, distances are equal for all IMT-2000 versions, while for the narrowband JTCTS waveform, the wideband CDMA IMT-2000 implementation results in a slightly lower separation distance.

Tables D-20 and D-21 show that the required separation distances are quite high (100 to 400 km), even for the higher interference thresholds. They are higher than those shown for the TACTS/ACMI transmitters, primarily because of the higher EIRP of the JTCTS equipment. Depending on the interference criterion used, coordination to line of sight distances may be necessary to avoid interference from the airborne system to the IMT-2000 receivers.

Table D-20. Required Separation Distances, in km, to Preclude Interference from JTCTS Wideband Airborne Transmitters into IMT-2000 Receivers

IMT-2000 Station					
Mobile			Base		
CDMA WB	CDMA NB	TDMA	CDMA WB	CDMA NB	TDMA
IMT-2000 Interference Criterion I/N = -6 dB					
343.6	343.6	343.6	415.9	415.9	415.9
IMT-2000 Interference Criterion for S = Sensitivity + 10 dB					
187.0	187.0	187.0	399.7	399.7	399.7
IMT-2000 Interference Criterion for S = Sensitivity + 20 dB					
55.2	55.2	55.2	157.3	157.3	157.3

Table D-21. Required Separation Distances, in km, to Preclude Interference from JTCTS Narrowband Airborne Transmitters into IMT-2000 Receivers

IMT-2000 Station					
Mobile			Base		
CDMA WB	CDMA NB	TDMA	CDMA WB	CDMA NB	TDMA
IMT-2000 Interference Criterion I/N = -6 dB					
346	351.4	351.4	417	420	420
IMT-2000 Interference Criterion for S = Sensitivity + 10 dB					
212	283.7	283.7	400	402	402
IMT-2000 Interference Criterion for S = Sensitivity + 20 dB					
62.8	84.1	84.1	179	238	238

D.4.3 Mitigation Techniques

Possible methods to mitigate interference between IMT-2000 and ACTS equipment include the following. These techniques were generally found to be not practical or operationally unacceptable.

- Coordination of antenna orientation of IMT-2000 base stations with the location of the training ranges. The mainbeams of the IMT-2000 antennas should not point in the direction of training range ground stations or of major flight activity, and the IMT-2000 base stations should not be illuminated by the mainbeams of high-gain ACTS ground station antennas.
- Coordination of training range aircraft training schedules with IMT-2000 operations, such that IMT-2000 power levels, frequencies, or antenna orientations could be adjusted to avoid mutual interference.
- Use of polarization diversity between IMT-2000 base stations and ACTS equipment, to reduce interference levels for mainbeam-to-mainbeam interactions between IMT-2000 and ACTS equipment.

D.4.4 Results – Option 1

1. Because of the large separation distances needed to avoid interference from airborne ACTS transmitters to IMT-2000 receivers, and because of the effect of the aggregate IMT-2000 ground environment on the link margins of the airborne ACTS receivers, sharing of the two systems, without frequency separation, does not appear feasible.

2. Interference between airborne ACTS transmitters and IMT-2000 receivers and between the aggregate IMT-2000 environment and ACTS airborne receivers seem to be the worst, or most limiting, cases, for band sharing.

3. A 10 dB reduction of aggregate interference power, as might be associated with an incomplete buildup of a mature IMT-2000 environment, still results in negative link margins for TACTS/ACMI and JTCTS airborne receivers.

4. For ground-to-ground interactions, separation distances to avoid interference appear to be of the same order of magnitude for ACTS-to-IMT-2000 and IMT-2000-to-ACTS interactions. Effects on system operation depend on interference thresholds used and the location of the ACTS ground equipment.

D.4.5 Operational Impact

Full band sharing of the 1755-1850 MHz spectrum with ACTS and IMT-2000 is not considered to be a viable option. As reported in the DoD IMT-2000 Technical Working Group Interim Report, the results of the full band sharing electromagnetic compatibility (EMC) assessment indicates that significant undesired interactions may occur both to and from ACTS. Distance separations needed to preclude interference can be substantial, particularly in the case of airborne platforms. Overseas ACTS ranges experiencing undesired interactions from cellular phone communications confirm this assessment. Coordination and scheduling of shared spectrum between DoD training ranges and IMT-2000 is not possible due to mission classification, complex range operations, and allowing immediate support of unplanned training exercises. Also, training missions continue to require increased range airspace. Operational limitations and constraints cannot be placed on missions supporting warfighter training. Spectrum sharing would further negatively impact-training operations by restricting tethered RF connectivity & operations of ACTS pods with the range ground system infrastructure. It would also restrict available range airspace, which negatively affects training in the use of simulated munitions systems. It limits training mission scheduling and live monitoring capabilities. It would constrain ACTS interoperability and compatibility. Sharing would limit or preclude large-scale joint training exercises and limit migration to rangeless air-to-air operational training.

Under the program of record, JTCTS will not be deployed in CONUS by 2003. It is anticipated that under full band sharing in this time frame, all current TACTS/ACMI would be forced to cease operation. The absence of instrumentation to support live tactical training would result in direct loss of readiness for combat forces. The ability to observe, evaluate, and provide feedback for complex, multi-faceted training exercises would be virtually eliminated. Losing the instrumentation capabilities would remove the source of objective information. Lack of simulation capabilities would negate the ability to determine force attrition in real-time for realistic evaluation of tactics and tactical execution.

Under current plans the replacement of legacy TACTS/ACMI by JTCTS will not begin until post 2006 although fixed range development will be ongoing. In the 2006 time frame some data link modifications could be made, and if started soon enough, an acceleration of the program to replace the legacy TACTS/ACMI could make significant progress by 2006—but complete conversion of legacy systems by that time frame is not considered achievable. However, even with a conversion to JTCTS, there are no mitigation techniques that could be implemented in either JTCTS, legacy TACTS/ACMI, or IMT-2000 in the same geographic region.

D.5 OPTION 2 – BAND SEGMENTATION/PARTIAL BAND SHARING

The analysis described in the previous sections assumed no separation in frequency between the IMT-2000 and ACTS systems. If the present band is segmented, with separate but adjacent segments allocated separately to ACTS and IMT-2000 systems, the effect of frequency separation between the two systems becomes of importance.

Two proposed methods for operating within the 1755 to 1850 MHz band were examined briefly, and the feasibility of satisfactory operation of the ACTS and IMT-2000 equipment was assessed.

In the first plan (Option 2A), the 1755-1805 MHz portion of the band remains allocated to ACTS. The rest of the band is allocated to IMT-2000 systems. In the second plan (Option 2B), ACTS and IMT-2000 are allowed to operate in the present band. The ACTS systems operate as they presently do, and the IMT-2000 systems must operate in the 1755-1790 MHz portion of the band and coordinate in the areas where ACTS operates and where interference is a possibility. The 1790-1850 MHz portion of the band is retained for use by ACTS systems.

D.5.1 Option 2A – 1755-1805 MHz Retained

D.5.1.1 TACTS/ACMI Technical Assessment

Under plan 1 (Option 2A), the TACTS/ACMI would lose six of the 11 frequencies now available to it across the 1768 to 1840 MHz range. It would lose use of the 1840 MHz (A) or 1830 MHz (B) ground-to-air link transmit frequencies, and four of the six frequencies (1807, 1812, 1817, and 1822 MHz) used for transmitting from the remote ground transmitters to the master receiver. Typically, the TACTS/ACMI uses eight or more frequencies for its necessary functions. Loss of all but the 1755-1805 MHz portion of the band does not appear feasible for satisfactory operation of the present TACTS/ACMI system.

A short EMC analysis to determine the feasibility of modifying the TACTS/ACMI to operate in the 1755-1805 MHz band was performed. Minimum frequency and distance separations such that an interference threshold was not exceeded were calculated. The interference thresholds used were the same as those in the sharing analysis. The minimum frequency separation to avoid interference between adjacent ranges was calculated to be 5 MHz, for the AIS transmitter and TIS downlink receiver. It was also determined that a frequency separation of 4.8 MHz from the band edge is necessary to avoid interference from the AIS transmitter to IMT-2000 base station receivers at the band edge, with no distance constraints.

Frequency and distance separation constraints are expected to be similar between the AIS transmitter and remote ground receivers, as between the A/G downlink transmitter and G/A downlink receiver.

It is assumed that the master station transmitter frequency is 3 MHz from the band edge, and the "B" downlink frequency is 5 MHz removed from that. Further, the "A" uplink frequency is assumed to be 5 MHz removed from the upper band edge, with the remote transmitter frequencies at least 5 MHz from the uplink or downlink frequencies. With these assumptions, the frequency plan of Table D-22 is possible.

Table D-22. Possible TACTS/ACMI Frequency Plan for 1755-1805 MHz

Frequency, MHz	Link Description
1758	Master to Remotes
1763	AIS-to-Remote Downlink "B"
1768	AIS-to-Remote Downlink "A"
1773	Remote-to-Master 1
1778	Remote-to-Master 2
1783	Remote-to-Master 3
1788	Remote-to-Master 4
1795	Remote-to-AIS Uplink B
1800	Remote-to-AIS Uplink A

Using the arrangement of Table D-22, four remote G/G frequencies are available, compared to the six presently used. The possibility of compressing six G/G frequencies into the 27 MHz of available spectrum between the downlink "A" and uplink "B" frequencies was not analyzed. Also, a more detailed EMC analysis of the TACTS/ACMI components should be conducted. The frequency separation between collocated AIS transmitters and receivers is reduced from 52 MHz to 32 MHz. A 4 dB increase in transmitter-to-receiver isolation from that now employed, to compensate for decreased rejection due to offtuning, would be necessary.

Without modification of the TACTS/ACMI emission bandwidth or receiver selectivity characteristics, the electromagnetic interference (EMI) margin of the modified system will be reduced from that of the present system. A major modification of the TACTS/ACMI, such as using GPS for position determination, would allow the bandwidths of the air-to-ground (A/G) and ground-to-air (G/A) signals to be reduced from 3 MHz to a value closer to the present data rate, 198 kHz. Thereby, the amount of spectrum needed would be reduced further. Also, since multilateration is no longer needed, the number of ground-to-ground (G/G) frequencies would be reduced from the six presently used to one or two.

D.5.1.2 JTCTS Technical Assessment

The JTCTS normally uses one to three frequencies between 1710 and 1850 MHz. This range is further restricted to 1755-1850 MHz in the US and Possessions. One frequency is used for air-to-air communications, the primary link. A second frequency is often used for the secondary link, for ground-to-air communications. The third frequency is used for a tertiary data link for ground to ground communications. This link is not always used.

In conversations with JTCTS engineers at SRI International, it has been stated that it may be possible for the JTCTS to operate with two 22.5 MHz channels separated by 5 MHz at the –20 dB points of the spectrum. The total occupied bandwidth for the wideband mode would be approximately 22.5 x 2 + 5 = 50 MHz. The third frequency, for the tertiary link, could be reassigned to a different, probably a higher, band. It may be possible that the two channels can operate without mutual interference, as has been stated. However, the effect of JTCTS interactions with IMT-2000 equipment near the edges of the band must also be investigated. A preliminary assessment of the effects of frequency separation was made by generating frequency-distance curves for JTCTS-to-IMT-2000 and IMT-2000-to-JTCTS interactions. The curves generated are for wideband CDMA and wideband JTCTS versions. The middle CDMA interference threshold was used, corresponding to a desired signal 10 dB above sensitivity. These curves are given as Figures D-2 and D-3. Although conservative interference thresholds were used in generating these curves, they show that, at the band edges, 11.25 MHz from the JTCTS wideband center frequency, significant separation distances are needed to avoid interference. Further investigations of these interactions would be necessary to determine the feasibility of this band segmenting plan.

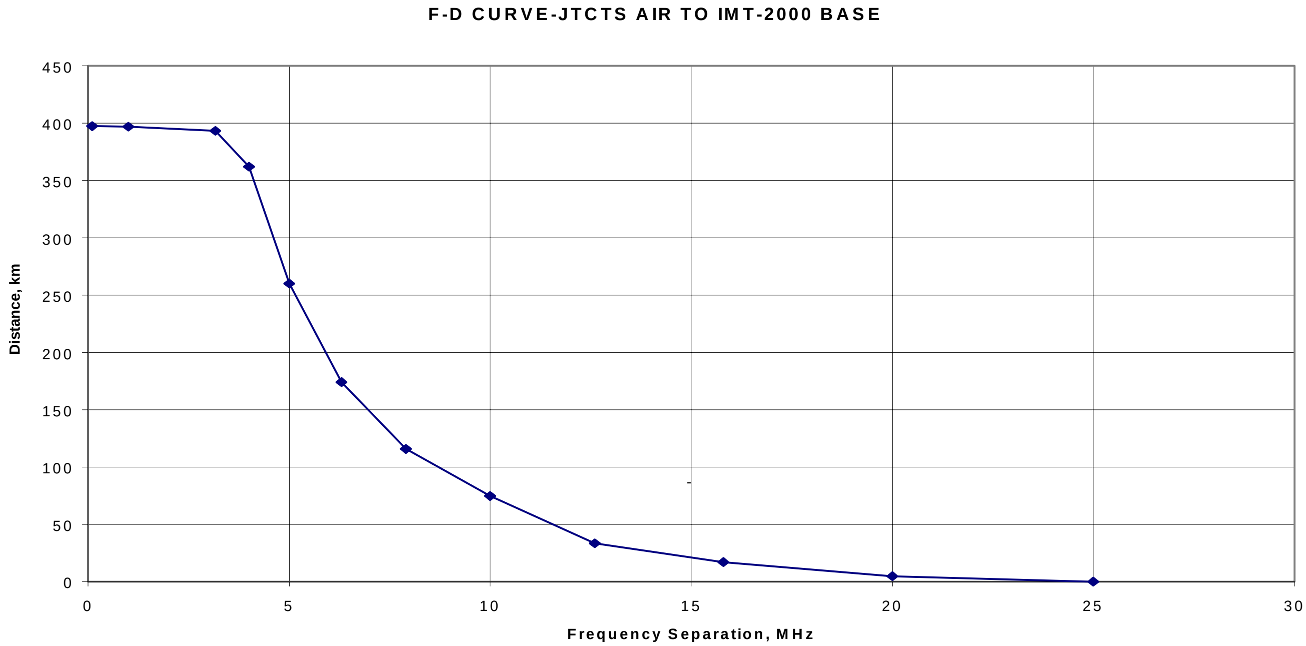

Figure D-2. Frequency-Distance Curve for JTCTS Airborne to IMT-2000 Interaction

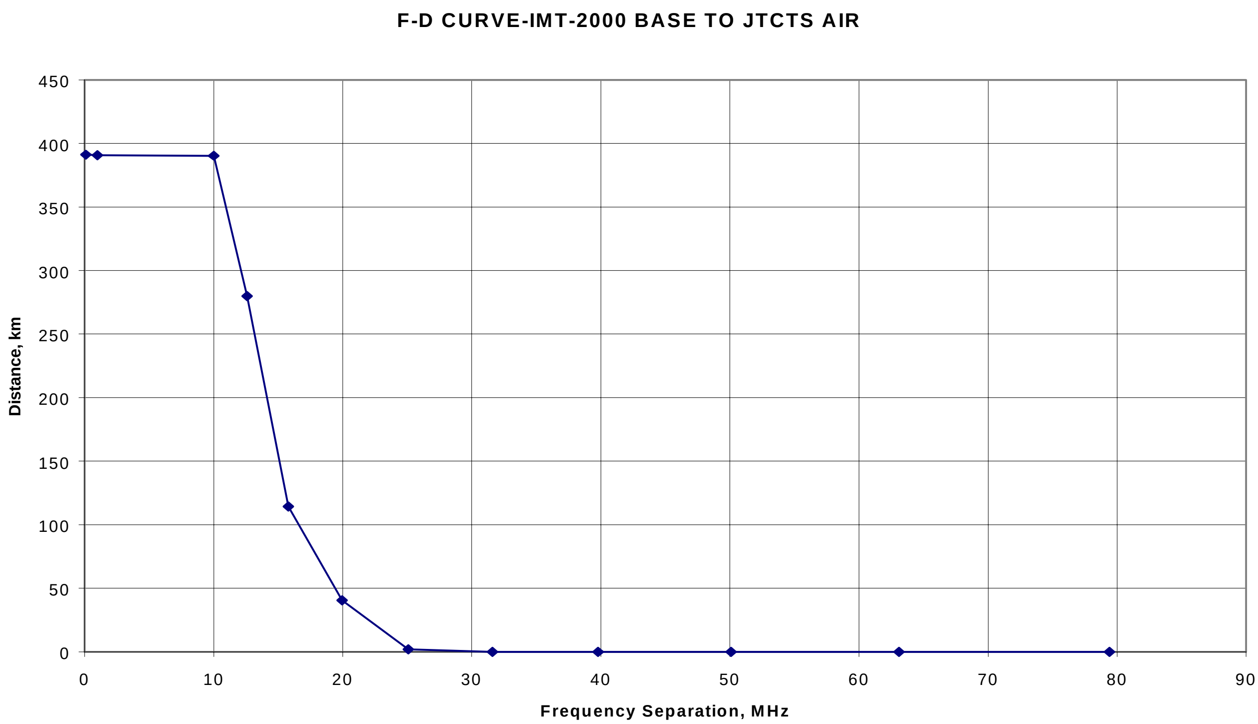

Figure D-3. Frequency-Distance Curve for IMT-2000 to JTCTS Airborne Interaction

D.5.1.3 Operational Impact

Interference with the ACTS data link will occur dependent on frequency, location, and transmitter power of future IMT-2000 equipment. The RF interference will adversely affect system operation. Interference with uplink frequencies (1830 and 1840 MHz) will render ACTS airborne instrumentation inoperative while interference with ACTS ground-to-ground RF links could vary with portions of the range becoming inoperative. Additionally, there is no current way to limit system operation to a portion of the band, therefore it must be assumed ACTS operation will adversely affect IMT-2000 systems. This would likely cause severe restrictions to TACTS/ACMI emissions thus significantly reducing system utility.

If the ACTS loses access to the 1805-1850 MHz band in 2006, the impacts would be similar to those described for 2003 unless modification to the existing frequency plan is pursued. A remanufacture of existing TACTS/ACMI hardware (updating for obsolescence and technology advances) could make operation of the legacy systems within a reduced bandwidth feasible. It is estimated the fielding of the proposed ACTS modifications could be accomplished for all ranges by 2006. However, operational training will be impacted because of range downtime during installation and checkout of the modifications. Each range will be completely down for at least 1-3 months with limited capability up to 6 months due to modification of range equipment. A moderate schedule risk is assessed in modifying all the ACTS ranges by 2006. For 2010, the assessment is the same as the assessment for provided 2006 except that risk is reduced based on additional time to deploy.

The operational impact can be minimized if no spectrum conflicts arise with other Government systems and all the mitigation efforts are completely implemented by 2006 (schedule risk) or if turnover of 1805-1850 MHz band can be delayed at sites where mitigation measures have not been completed by 2006.

The replacement of the legacy ACTS by JTCTS is scheduled to begin after 2006. The 2010 time frame may allow for an accelerated JTCTS program to provide replacement ACTS, provided actions are taken sufficiently early. A modification program for the legacy ACTS could also be completed by that time frame—but that would be moot if all systems have been replaced by JTCTS. Any loss of current system use or functionality would impact the training and readiness of the aircrews, with the impact directly related to the historical tactical training role/function of the system at a given site.

D.5.2 Option 2B – Phased Segmentation to 1790-1850 MHz Retained

D.5.2.1 TACTS/ACMI Technical Assessment

In Option 2B, which involves coordination within the same band, IMT-2000 systems would be forced to coordinate their operation in areas where present ACTS systems operate and interference is a possibility. In the first segment of the band to be made available, 1710 to 1755 MHz, no TACTS/ACMI frequencies exist, and JTCTS does not normally operate in this range in the US and Possessions. For the other segments (1755 to 1780 and 1780 to 1790 MHz), airborne and ground-based TACTS/ACMI frequencies are used. The results of the previous sharing analysis show that, for the airborne ACTS transmitters, coordination distances to avoid interference to an IMT-2000 receiver are sometimes at line-of-sight distances (400 km for 9000 m altitude). Distances needed to avoid interference from aggregate IMT-2000 environments to an airborne ACTS receiver are more difficult to calculate. However, with a single metropolitan area the size of Las Vegas, NV, and ignoring the effects of other cities, preliminary calculations indicate that separation distances of the same magnitude or larger may be needed.

The possibility of modifying the TACTS/ACMI such that all frequencies, A/G, G/A, and G/G, are within the 1790-1850 MHz band, and sharing is not necessary, was also considered. The analysis, results, and frequency plan described in Section 5.1.2.1 apply to this case also, with one exception. That is, the amount of spectrum available between the downlink "A" and uplink "B" frequencies, for remote (G/G) links, is increased from 27 to 37 MHz. Allowing 10 MHz for protection between G/G and A/G or G/A links, 27 MHz are left. This amount of spectrum allows for six G/G frequencies separated by 5 MHz, which is the present arrangement. The frequency separation between collocated AIS transmitters and receivers is reduced from 52 to 42 MHz. A 2 dB increase in transmitter-to-receiver isolation, to compensate for decreased rejection due to offtuning, would be necessary. As with the 1755-1805 MHz band the EMI margin would be reduced when compared to that of the present system, with the present emission bandwidth and receiver characteristics. Further modification of the TACTS/ACMI, to provide position determination by GPS, would reduce the bandwidth of the A/G and G/A emissions, and greatly reduce the number of G/G frequencies needed.

D.5.2.2 JTCTS Technical Assessment

Although JTCTS is capable of operating in the first part of the band to be shared in this option, 1710-1755 MHz, it does not normally operate in this segment in the US and Possessions. For the rest of the proposed shared band, 1755 to 1780 and 1780 to 1790 MHz, separation distances needed to avoid interference from the airborne JTCTS and IMT-2000 receivers, as well as from an aggregate environment of IMT-2000 transmitters to the JTCTS receiver, are estimated to approach line of sight magnitudes. Operation in the 1790-1850 MHz band, the part left unshared, would allow at most two of the three data links to operate compatibly.

D.5.2.3 Operational Impact

Under this option, if IMT 2000 build out is contained below 1755 MHz until perhaps the 2006 time frame, there would be little impact to DoD operations during that time as ACTS frequencies begin above 1755 MHz. As IMT 2000 equipment is deployed to use frequencies above 1755 MHz, impacts to TACTS/ACMI would occur. Under the program of record, the replacement of the legacy TACTS/ACMI by JTCTS will not yet have begun in 2006 although fixed range development will be ongoing. The 2006 time frame may allow for the replacement of legacy TACTS/ACMI only by a drastically accelerated JTCTS program, but the schedule realism for replacement of all legacy TACTS/ACMI by either the current JTCTS or a modified JTCTS in that time frame is questionable. If started soon enough, a simple modification program for the legacy TACTS/ACMI could allow it to keep operating in 1780-1850 MHz band. This would allow sufficient time (i.e., until 2010) for all legacy TACTS/ACMI to be replaced by JTCTS. The ground-to-ground microwave links can be relocated once suitable spectrum is identified. Operational impact is none if no spectrum conflicts arise with other Government systems and all the mitigation efforts are completely implemented by 2006 (schedule risk) or if turnover of 1755-1780 MHz band can be delayed at sites where mitigation measures have not been completed by 2006. Any loss of current system use or functionality would impact the training and readiness of the aircrews, with the impact directly related to the historical tactical training role/function of the system at a given site.

The replacement of the legacy ACTS by JTCTS is scheduled to begin after 2006. The 2010 time frame may allow for an accelerated JTCTS program to provide replacement of ACTS, provided actions are taken sufficiently early. A modification program for the legacy ACTS could also be completed by that time frame—but that would be moot if all systems have been replaced by JTCTS. Any loss of current system use or functionality would impact the training and readiness of the aircrews, with the impact directly related to the historical tactical training role/function of the system at a given site.

D.5.3 Results – Option 2

1. Of the band-segmenting plans proposed, plan 1 (Option 2A) involves use of only the 1755-1805 MHz portion of the band. Operation of the present TACTS/ACMI does not appear feasible with this plan. Operation of a modified TACTS/ACMI may be feasible, with a reduced number of G/A

link frequencies and/or reduced EMI margin. Further, modification of TACTS /ACMI to use GPS for position determination would greatly reduce the number of required G/G frequencies. Operation of the JTCTS may be possible with reassignment of one of the three channels. Interactions of JTCTS with IMT-2000 equipment in adjacent bands need to be investigated further before feasibility of this option can be demonstrated.

2. Segmentation plan 2 (Option 2B) involves coordination of IMT-2000 operations in regions where ACTS systems presently operate and interference is possible. For the portions of the band above 1755 MHz, preliminary analysis, as discussed in this report, indicates that, because of the use of airborne ACTS transmitters and receivers, coordination distances from flight areas may exceed 400 km, making partial band sharing with this plan difficult to implement. Operation of a TACTS/ACMI modified such that all frequencies are within the 1790-1850 MHz band may be feasible, with a somewhat reduced EMI margin, or with position determination using GPS.

3. Interference problems exist in implementing both segmenting Options 2A and 2B, with the present TACTS/ACMI. With Option 2A, operation of the present TACTS/ACMI is not feasible. With Option 2B, partial band sharing with the present TACTS/ACMI would lead to required separation distances approaching radio line-of-sight. Modifications of TACTS/ACMI may make operation in the restricted bands feasible, for both Options 2A and 2B. For both Options 2A and 2B, operation of JTCTS, with the tertiary data link assigned to a different band, may be feasible. However, further investigation is needed to verify this conclusion.

D.6 OPTION 3 – PARTIAL BAND SEGMENTATION/OTHER BAND COMBINATION

D.6.1 Technical Assessment

In the analysis described here, the effects of loss of part of the 1755-1850 MHz band are treated. Operation is permitted for ACTS in the 1755-1805 MHz (or 1790-1850 MHz) portion of the band, while the remainder of the band is reallocated to IMT-2000 use. The focus of this analysis was on the 1755-1805 MHz portion of the band. Both the 1755-1805 and 1790-1850 MHz portions of the band are in the frequency ranges of the TACTS/ACMI and JTCTS. Although the 1790-1850 MHz portion is 10 MHz larger than the 1755-1805 MHz portion considered, most of the conclusions should be generally applicable to both plans. The ground-to-air (G/A), air-to-ground (A/G), and air-to-air (A/A) links are assumed to remain in the 1755-1805 (or 1790-1850) MHz band, while the ground-to-ground (G/G) links of each system are moved in frequency to higher bands. The two bands considered for G/G fixed point-to-point communication are 4400-4940 MHz and 7250-8400 MHz. Feasibility, self-interference, and interference to and from incumbent systems in the band were considered.

D.6.1.1 TACTS/ACMI

D.6.1.1.1 SELF-COMPATIBILITY ANALYSIS

For each system, the reduced available bandwidth means not only that components of the system must be reassigned to another band, but also that the frequency separations between those components remaining in the band are reduced. In both the TACTS/ACMI and JTCTS systems at present, the A/G and G/A (or A/A) link frequencies are generally near the band edge, with G/G link frequencies in the gap between the two sets. Under the proposed partial segmenting plan, the frequency gap is removed and the A/G, G/A, and/or A/A links are much closer together. This situation increases the potential for interference, both within the collocated transceivers and between adjacent ranges.

The TACTS/ACMI A/G and G/A links presently use four frequencies in the 1755-1850 MHz range. The two uplink frequencies (1840 MHz and 1830 MHz) are called A and B frequencies, respectively, and are separated by 10 MHz to avoid mutual interference problems at adjoining training ranges. The two downlink frequencies, 1788 and 1778 MHz, are also A and B frequencies, and are separated for the same reason. The transmit and receive frequencies are separated by 52 MHz to allow for isolation between the collocated airborne or ground-based transmitter and receiver.

The feasibility of using a set of four frequencies with reduced separation to fit within the 1755-1805 MHz band was investigated. A frequency plan for the 50-MHz band segment was proposed for study. The G/A frequencies are 1763 MHz (B) and 1773 MHz (A) and the A/G frequencies are 1787 MHz (B) and 1797 MHz (A). The 10-MHz frequency separation between B and A frequencies is preserved, the separation between transmitter and receiver frequencies is reduced from 52 to 24 MHz, and the separation from band edges is reduced from 15 to 8 MHz.

Frequency Separations Needed for Adjacent Ranges. Calculations of necessary frequency and distance separation to avoid interference were made. For the AIS transmitter and TIS receiver, it was found that 5 MHz separation is needed between adjacent ranges, to avoid the necessity of a specified distance separation.

Frequency Separation or Isolation Needed for Simultaneous A/G and G/A Communication. For the collocated transmitter and receiver, airborne or ground-based, with the

52-MHz separation used at present, a rejection of 82.3 dB due to off-tuning was calculated. An additional 77.7 dB of isolation is needed to avoid interference. Reducing the frequency separation to 24 MHz leads to a 76 dB value of FDR, or a 84 dB loss needed from other isolation. This value is 6.3 dB more than that attained at present. If TACTS/ACMI were redesigned to use GPS for position determination, the bandwidths of the A/G and G/A signals could be reduced from 3 MHz to a value closer to that of the present data rate, 198 kHz, and further reduce the amount of spectrum needed in the reduced band.

Analysis of System EMI at Band Edges with IMT-2000 Equipment. For the TACTS/ACMI AIS transmitter, a frequency separation of 4.8 MHz from the band edge is necessary for no distance constraints to avoid interference to IMT-2000 base station receivers at the band edge. Again the IMT-2000 interference threshold assumes the desired signal is 10 dB above the sensitivity level. The frequency plan for the TACTS/ACMI in the 1755-1805 MHz band, postulated earlier, assumes an 8-MHz frequency separation from the edge of the band. Hence the interference is below the IMT-2000 threshold.

Analysis of EMC with Other Systems in the 1755-1850 MHz or 1790-1850 MHz Band. The 1755-1850 MHz band is currently shared by TACTS/ACMI with tactical radio relay links and missile video and control links. Reduction of the available spectrum from 95 MHz to 50 (or 60) MHz means, for the TACTS/ACMI systems, that the G/G links would migrate to other bands. The A/G, and G/A links, because one or both ends are on an aircraft at an altitude that may reach 30,000 feet or more, may cause or suffer interference out to distances approaching radio line of sight (390 km at 30,000 ft.). EMC of the TACTS/ACMI with itself is difficult to attain in this band, especially when adjacent ranges are considered. For the JTCTS, self-compatibility, when adjacent ranges are considered, has not been predicted to be attainable through frequency separation alone. For the TACTS/ACMI, although EMC with itself is predicted to be attainable, interference from or to other systems in this band, such as tactical radio and missile control links, would add to a compatibility situation that is marginal at best.

D.6.1.1.2 Issues of Moving Ground-to-Ground Links to Other Bands

Issues of moving G/G links to higher bands are similar for both TACTS/ACMI and JTCTS. The exception to this rule is that TACTS/ACMI uses a large number, up to 20 or more, of ground-to-ground links to provide position location by multilateration, while JTCTS uses only one ground-to-ground link to transmit data to the control station for monitoring or other purposes. The main part of the analysis will be included under the TACTS/ACMI section, with exceptions to the conclusions noted for JTCTS.

Issues associated with moving the ground-to-ground links of the TACTS/ACMI and JTCTS to other frequency bands include feasibility, e.g., propagation phenomena and hardware issues that may affect link redesign, and potential EMC problems with equipment presently in the band of concern. These issues were explored for the 4400-4940 MHz and 7250-8400 MHz bands.

Feasibility Assessment—Fade Margin and Link Length. An approximation of the relationship between link reliability, fade margin, link length, and frequency is given by Equation D-6:[18]

$$U_{ndp} \quad = \quad a\, b\, (2.5 \times 10^{-6})\, f\, D^{3}\, 10^{-F/10} \qquad \text{(D-6)}$$

Where:

U_{ndp}	=	annual outage probability (1 - reliability)
a	=	terrain factor
b	=	climate factor
F	=	fade margin, to the "minimum acceptable" point, in dB
D	=	path length, in miles
f	=	frequency, in GHz

The product of a and b equals 0.25, for a normal or average path.

A previous Electromagnetic Compatibility Analysis Center (ECAC) report dealt with site selection of proposed ACMI facilities at Holloman AFB, NM.[19] The length of the master-to-remote paths varies from 8 to 50 km (5 to 31 mi). For a 50 km (31 mi) path, and a link reliability of 99.99 percent (U_{ndp} = 0.0001), use of Equation D-6 results in a 25.3 dB fade margin needed for 1.8 GHz. To preserve the same link reliability with the same fade margin at 4.4 GHz, the link length would have to be reduced from 50 km to 36.6 km (22.75 mi). To retain the same link length, and hence the same tower sites, the fade margin would have to be increased to 29 dB. As an example, increasing the fade margin could be accomplished by increasing the effective radiated power output by 3.7 dB, or more than doubling the power.

To operate in the 7.25-8.4 GHz band, use of Equation D-6 shows that a 50 km link would have to be reduced to 30.8 km (19.1 mi) to preserve a 99.99 percent link reliability with a 25.3 dB fade margin, as

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[18] GTE Lenkurt Incorporated, *Engineering Considerations for Microwave Communications Systems,* San Carlos, CA, 1975, pp. 59-60.

[19] John Covert, *ACMI Siting and EMC Study for Holloman Air Force Base,* ECAC-CR-79-007, Annapolis, MD: DoD ECAC, January 1979.

predicted to occur at 1.8 GHz. To retain the same link length, the fade margin would have to be increased from 25.3 dB to 31.7 dB. As an example, increasing the fade margin could be accomplished by increasing the effective radiated power, by about 6 dB, or a factor of x4.

Feasibility Assessment—Power, Noise Figure, and Antenna Gain Considerations. The TACTS/ACMI TIS remotes use transmitters with 1 to 5 watts (30-37 dBm) of power. Transmitter powers in this range appear to be readily available throughout the frequency ranges from 1 to 8 GHz.[20] If the link lengths were kept the same and the fade margin increased, say, to 29 dB as calculated above, this would be an increase of 4 dB. A total of 20 log (4800/1800) = 8.5 dB of additional path loss would be expected. The antenna gain for a parabolic antenna of a given size would increase by 8.5 dB also. Use of matching high-gain antennas on each end of the link could increase the total coupling gain by 8.5 dB, so the transmitter power would not need to be increased.

The TACTS/ACMI receivers at 1.8 GHz have noise figures in the order of 2-3 dB. While Reference 20 shows a number of available receivers with noise figures in that range at 2 GHz, they are much less common at higher frequencies. At 4 GHz, they range from 5 to 8 dB, and at 8 GHz, from 8 to 8.5 dB. More recent manufacturers' data, however, shows that low-noise amplifiers with noise figures less than 2 dB are readily available, at least in commercial versions, for frequencies at and above 10 GHz.[21]

To provide the increased fade margin needed, an increase of 6.4 dB in received power would be needed. At the higher frequency, an increase in 12.7 dB in antenna gain could be realized for a given antenna size. If matching antennas were used on each end of the link, the coupling loss would be decreased by this amount, making up for the necessary 6.4 dB increase in received power to attain the same link reliability. As was stated previously, amplifiers with noise figures less than or equal to the 2.3 dB known to be used by the TACTS/ACMI systems should be readily available.

Self-Interference Potential. Issues associated with interference between the ACTS links should be no different than for their present configuration. With the TACTS/ACMI, the problem at certain ranges, such as Fallon, which lists 23 links,[22] using six frequencies among them, is expected to be severe but apparently tractable. If more bandwidth is available, however, the resulting increase in frequency resources would lessen the problem. A proposed modification to TACTS/ACMI, to use GPS for

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[20] *MSN Microwave Radio System Matrix,* Microwave Systems News, June 1980, pp. 92-108.

[21] Manufacturers Data from JCA Technology and MITEQ, *Microwaves & RF,* September 2000.

[22] Mike Ryan, Mid-Atlantic Area Frequency Coordination Office, Naval Air Warfare Center Aircraft Division, facsimile to Bob Martin and Al Baker, JSC/IITRI, , Patuxent River, MD, October 2000.

position determination, would also reduce the number of links to one, eliminating the potential for self-interference.

Self-interference potential in the 7250-8400 MHz band should be similar to that described for the 4400-4940 MHz band. Because the band is larger (1150 MHz) than at 4400 MHz (540 MHz) more frequency resources may be available than at the lower band, as well as in the present 95-MHz band (1755-1850 MHz).

EMC with Incumbent Equipment—4400-4940 MHz. The AN/TRC-170 and AN/GRC-222 are tactical radios used in both line-of-sight (LOS) and troposcatter modes. They use high-gain antennas, and compatibility of the ACTS fixed G/G links with these systems should be attainable using a combination of frequency and distance separation and antenna pointing discrimination.

The Light Airborne Multipurpose System (LAMPS) is operated primarily in an ocean environment and is not expected to interact with G/G links at training ranges under most conditions. For CEC, band sharing is not possible between CEC and the relocated ground-to-ground links that support an air combat training system for sites where both systems operate simultaneously. Band segmentation would, among other things, preclude fully integrated training with an attendant and unacceptable reduction in readiness.

Other equipment in the 4400-4940 MHz range includes threat simulators, which are assigned frequencies in the 4900-4990 MHz range at the Naval Air Station (NAS) Oceana training range (Reference 22). In selecting operating frequencies for the ACTS G/G links, the part of this segment overlapping the 4400-4940 MHz frequency range would need to be avoided.

EMC with Incumbent Equipment—7250-8400 MHz. Equipment presently in this band includes point-to-point communications links, and earth-to-space and space-to-earth communications links. According to Reference 22, a number of frequency assignments associated with US Navy training ranges are in this band. These assignments include those for threat simulators at NAS Oceana (7800-8500 MHz) and MCAS Yuma (7950-8020 MHz). A number of microwave links are also operating at frequencies throughout the 7250-8400 MHz range. Frequency assignments for these links include five at Cherry Point, 15 at Camp Lejeune, and nine at Fallon. EMC with these existing threat simulators and any associated airborne jammers, as well as with the existing point-to-point links at the three bases mentioned would have to be considered. Since a number of bands appear to be used for these point-to-point links at different ranges, it may be feasible to reassign the existing point-to-point links to a band higher than 7250-8400 MHz, in order to effect common TACTS/ACMI or JTCTS frequencies.

D.6.1.2 JTCTS

D.6.1.2.1 Self-Compatibility Analysis

The present JTCTS, when the maximum number of frequencies are used, consists of three links, the primary channel, or air-to-air link, the secondary channel, or ground-to-air link, and the tertiary channel, or ground-to-ground link. Each channel can be tuned to a center frequency between 1710 MHz and 1850 MHz (in 5-MHz increments) (In the US and possessions, the frequency range of operation is 1755-1850 MHz.) However, an example of spectrum usage that has been proposed has the primary and secondary channels near each edge of the range, with the tertiary channel frequency between the other two (Reference 11). With a 50-MHz frequency range available, the tertiary channel will be reassigned to another band, and it has been proposed that the remaining channels will be assigned so that their -20 dB emission levels are at the band edges. For the JTCTS wideband mode, the -20 dB points are at 11.25 MHz from the center frequencies. Therefore, the center frequencies of the primary and secondary links will be separated by 27.5 MHz. The analysis in this section was conducted assuming the JTCTS wideband mode was used.

Provisions for Adjacent Ranges. Calculations were made of the distance separations necessary to avoid interference, for the JTCTS G/A transmitter to the JTCTS air-to-air receiver, with a 27.5 MHz separation between frequencies. The interference threshold used was an interference-to-noise ratio of -6 dB, which leads to a 10 percent decrease in maximum communications range. This frequency separation allows the transmitter spectrums for both transmitters to be 20 dB down at the edge of the 1755-1805-MHz band. With this frequency separation, 76 km distance separation is needed to avoid interference. The same distance separation applies to the cases of an airborne transmitter and a ground based receiver, and to an airborne transmitter to an airborne receiver. A frequency separation of 35 MHz is necessary to lower the distance to 20 km. The above distance assumed all transmitters used the high-power wideband mode of JTCTS. If the low-power mode is used, the separation distance at 27.5 MHz frequency separation is lowered to 25 km, and a 28.4 MHz frequency separation is needed at 20 km.

Several TACTS/ACMI ranges on the east coast are approximately 100 nmi (185 km) apart and use alternating A and B frequency sets.[23] At 185 km a 22.8 MHz frequency separation is necessary, to avoid interference between two JTCTS systems. While this separation would allow two air-to-air links in the same band, interference to the ground-to-air links of the adjacent range, if present, would occur.

[23] James C. Hodges, *Frequency Management and Avoidance of Mutual Interference Between the TACTS and ACMI Ranges in the Eastern United States*, SRI International, 12 December 1983.

Frequency separation between adjacent ranges is not practical if both primary (A/A) and secondary (G/A) links occupy the same band.

Two other ideas are being explored for using JTCTS at adjacent ranges.[24] They are: using different spreading codes that are nearly orthogonal to provide additional isolation, and using timing discrimination between adjacent ranges, where combined usage of the two ranges does not exceed the maximum capacity of the system.

If it is possible to control the relative timing of the transmitted signals, the coded signals can be made nearly orthogonal, the effect of the added signal will be minimal, and only the noise added by the channel will be significant.[25] It may be possible to control this relative timing in cases where two ranges have access to a common control center, as is the case for the present two-master-station Charleston TACTS range (Reference 23). However, most adjacent ranges do not at present operate with common control elements. If the timing between two adjacent ranges is not controlled, the interfering signal will appear to be noiselike. It will be equivalent to that analyzed in this study, and will be subject to the same frequency and distance constraints to avoid interference. The presence of dispersion due to multipath also degrades the orthogonality and increases the noise-like nature of the interfering signal.

The second technique mentioned requires timing discrimination at adjacent ranges and also assumes that the combined usage of the two ranges would not exceed the total capacity of the system (100 aircraft). For example, it is not envisioned that either the Yuma or Goldwater ranges would ever use more than 50 aircraft each during a training operation (Reference 24). The time-division multiple access scheme would provide enough time slots for aircraft in the two ranges. They could conceivably be run as one range (all on the same primary frequency) with a subset of data being routed to each. This technique would depend on the ability to coordinate the timing between the two ranges. A detailed examination of the feasibility of timing coordination was not conducted in this study.

Frequency Separation or Isolation Needed for Simultaneous A/A and G/A Communication. For the high-power transmitter situation, a 76-km separation in distance is needed to avoid interference at a 27.5 MHz frequency separation from the G/A transmitter to the A/A receiver, or from the A/A transmitter to a ground-based receiver. If operation in the low-power mode is used, as is presently being suggested for the secondary link (Reference 24), the necessary distance separation is

[24] David Hanz, SRI International, e-mail to Allan Baker, JSC/DWD, *Re: Additional Questions on JTCTS*, Menlo Park, CA, 6 December 2000.

[25] B. Paris, "Access Methods," Chapter 79 of J. Gibson, ed., *The Communications Handbook*, IEEE Press, 1999.

reduced to 25 km. The significance of this interference would depend on the period of time the secondary link is transmitting, and the airborne operations that are occurring during this time.

Analysis of System EMI at Band Edges with IMT-2000 Equipment. If the JTCTS signal is 11.25 MHz from the edge of the band, 42.4 km separation is needed from the IMT-2000 base station receivers at the band edge frequencies, to avoid interference. If no distance separation is observed, a frequency separation of 18.8 MHz is necessary. The interference threshold used assumed the desired signal was 10 dB above the sensitivity level. These distances may be significant, with training ranges near populated areas.

Analysis of EMC with Other Systems in the 1755-1850 MHz or 1790-1850 MHz Band. The 1755-1850 MHz band is currently shared by JTCTS with tactical radio relay links and missile video and control links. Reduction of the available spectrum from 95 MHz to 50 (or 60) MHz means, for the JTCTS systems, that the G/G, or tertiary, link would migrate to another band. The A/A and G/A links, because one or both ends are on an aircraft at an altitude that may reach 30,000 feet or more, may cause or suffer interference out to distances approaching radio line of sight (approximately 390 km at 30,000 ft.). EMC of the JTCTS with itself is difficult to attain in this band, especially when adjacent ranges are considered. For the JTCTS self-compatibility, when adjacent ranges are considered, has not been predicted to be attainable through frequency separation alone. If the interference margin is completely taken up by self-interference, addition of interference from other systems would lead to an incompatible situation..

D.6.1.2.2 Issues of Moving Ground-to-Ground Links to Other Bands

Feasibility Assessment—Fade Margin and Link Length. For the JTCTS, since position determination is done by the Global Positioning System (GPS) and not through multilateration, only one microwave link is needed for the tertiary link, to transmit data for monitoring purposes. The amount of equipment to be changed in frequency is therefore much less than for TACTS/ACMI. The power, antenna gain, and fade margin effects are expected to be the same. Modifications to TACTS/ACMI to use GPS for position determination have been suggested also. If such a modification were implemented, the number of microwave links needed for that system would also be decreased.

Feasibility Assessment—Power, Noise Figure, and Antenna Gain Considerations. The JTCTS receiver noise figure is 4.5 dB. Receivers with noise figures in this range in the 4 GHz band appear to be readily available.

Self-Interference Potential. With the JTCTS, if only one link is used, the potential for self-interference between ground-to-ground links should not exist.

EMC With Incumbent Equipment-4400-4940 MHz. For the JTCTS G/G link, the EMC situation with incumbent equipment in the 4400-4940 MHz band is similar to that with TACTS/ACMI, only with a single link instead of multiple links.

EMC With Incumbent Equipment-7250-8400 MHz. As was the case for the 4400-4940 MHz band, for the JTCTS G/G link, the EMC situation with incumbent equipment in the 7250-8400 MHz band is similar to that with TACTS/ACMI, only with a single link instead of multiple links.

D.6.1.3 Results – Option 3

1. It appears to be possible for the A/G and G/A links of TACTS/ACMI to operate in the 1755-1805 MHz (or 1790-1850 MHz) band compatibly, both within the same range and between adjacent ranges.
2. Operation of the A/A and G/A links of JTCTS within these restricted frequency bands may be feasible within the same training range, although some distance separation is necessary to avoid interference to IMT-2000 receivers at the band edges. Compatibility between adjacent ranges has not been demonstrated, and may not be attainable through frequency separation alone.
3. Because of the reduced spectrum available for all systems, and because the links remaining in the band have airborne transmitters and receivers, compatibility with equipment remaining in the band is expected to be made much more difficult to attain.
4. It appears to be feasible to move the G/G links of TACTS/ACMI and JTCTS to either the 4400-4940 MHz or 7250-8400 MHz band. Some equipment at training ranges is assigned frequencies in these ranges, including threat simulators and point-to-point microwave links. EMC problems with this equipment are expected to be tractable.
5. Redesigning the TACTS/ACMI to use GPS instead of multilateration for position determination would reduce the A/G and G/A signal bandwidths from 3 MHz to a value nearer the data rate (198 kHz) and make compatibility with itself and other systems easier to attain. It would also greatly reduce the number of G/G links to be redesigned to operate in another band.

D.6.2 Operational Impact

Interference with the ACTS data link will occur dependent on frequency, location, and transmitter power of future IMT-2000 equipment. The RF interference will adversely affect system operation. Interference with uplink and downlink frequencies will render ACTS airborne instrumentation inoperative while interference with ACTS ground-to-ground RF links could vary with portions of the range becoming inoperative. Additionally, there is no current way to limit system operation to a portion of the band, therefore it must be assumed ACTS operation will adversely affect IMT-2000 systems. This would likely cause severe restrictions to TACTS/ACMI emissions thus significantly reducing system utility.

If the ACTS loses access to parts of the 1755-1850 MHz band in 2006, the impacts would be similar to those described for 2003 unless modification to the existing frequency plan is pursued. A remanufacture of existing TACTS/ACMI hardware (updating for obsolescence and technology advances) could make operation of the legacy systems within a reduced bandwidth feasible. It is estimated the fielding of the proposed ACTS modifications could be accomplished for all ranges by 2006. However, operational training will be impacted because of range downtime during installation and checkout of the modifications. Each range will be completely down for at least 1-3 months with limited capability up to 6 months due to modification of range equipment. A moderate schedule risk is assessed in modifying all the ACTS ranges by 2006. For 2010, the assessment is the same as the assessment for provided 2006 except that risk is reduced based on additional time to deploy.

The operational impact can be minimized if no spectrum conflicts arise with other Government systems and all the mitigation efforts are completely implemented by 2006 (schedule risk) or if turnover of 1805-1850 MHz band can be delayed at sites where mitigation measures have not been completed by 2006. The operational impact may be further minimized if ground-to-ground links can be successfully relocated to other frequency bands. Compatibility with incumbent systems in the bands supporting relocation may be a major issue.

The replacement of the legacy ACTS by JTCTS is scheduled to begin after 2006. The 2010 time frame may allow for an accelerated JTCTS program to provide replacement ACTS, provided actions are taken sufficiently early. A modification program for the legacy ACTS could also be completed by that time frame—but that would be moot if all systems have been replaced by JTCTS. Any loss of current system use or functionality would impact the training and readiness of the aircrews, with the impact directly related to the historical tactical training role/function of the system at a given site.

D.7 OPTION 4 – VACATING THE 1755-1850 MHZ BAND

In Option 4, the 1755-1850 MHz band is unavailable, and all equipment must be redesigned to operate in other frequency bands that are allocated to their functions. For this option, both 2200-2290 MHz and 4400-4940 MHz were considered for moving the A/G, A/A, and G/A links. The two bands considered in Option 3, 4400-4940 MHz and 7250-8400 MHz, were again considered for the G/G links. Again, feasibility, self-interference, and interference to and from incumbent systems in the band were considered.

D.7.1 TACTS/ACMI Assessment

D.7.1.1 OPTION 4A – Move A/G and G/A Links to 2200-2290 MHz Band, and Move G/G Links to 4400-4940 or 7250-8400 MHz Band

With Option 4A, the entire 1755-1850 MHz band is no longer available for ACTS use. Instead of remaining in a reduced (50 MHz) portion of the present band, the A/G and G/A links of the TACTS/ACMI will be moved to a higher band. Two candidate bands were considered for this study. They are the 2200-2290 MHz and 4400-4940 MHz bands. For relocation of a system, especially one with airborne components, a number of issues must be addressed. The two primary categories of issues include the feasibility of redesigning equipment to perform its function in the new band, and potential EMC problems with equipment already using the band. The 2200-2290 MHz band was considered as a prime candidate for relocation. Because it is closest in frequency to the present band, it is expected to present a minimum number of redesign problems. However, it is already occupied by a number of systems considered to be of prime importance to the DoD and others. In addition, compatibility with other systems operating on board the platforms (aircraft or ship) where the system is installed, need to be investigated.

Systems presently residing in the 2200-2290 MHz band include Space-Ground Link Subsystem (SGLS) downlink receivers, missile telemetry links, threat simulators, and the NASA Goldstone Deep Space Network (DSN) and Space Tracking and Data Network (STDN) receivers located near one of the training ranges, at Fort Irwin, CA. At the Beaufort MCAS, eight microwave links are assigned frequencies from 2208 to 2285 MHz. On aircraft and ships, interference from the harmonics of collocated Joint Tactical Information Distribution System (JTIDS) and Tactical Air Navigation (TACAN) transmitters need to be considered. In addition, the effect of harmonics of the redesigned ACTS transmitter on collocated receivers needs to be assessed.

The effects of moving the G/G links to the 4400-4940 MHz or 7250-8400 MHz band has been treated in the previous section. For the 4400-4940 MHz band, an additional EMC issue has been created, because harmonics of transmitters in the 2200-2290 MHz band lie within this frequency range.

Feasibility Assessment. In the 2200-2290 MHz band, the free-space propagation loss is 1.9 dB higher than in the 1755-1850 MHz band. For G/A and A/G links, omnidirectional antennas are desirable, and no additional antenna gain can be achieved at the higher frequency, as may be the case with a dish antenna. Therefore, to maintain the same maximum communications range, the transmitter power needs to be raised by 1.9 dB. The TACTS/ACMI airborne transmitter power needs to be increased from 20 to about 30 watts. This power level is lower than the present JTCTS transmitter power of 67.6 watts, and therefore is considered to be feasible.

Self-Compatibility. In the analysis for the 1755-1850 MHz band, self-compatibility within this band segment was predicted for the TACTS/ACMI A/G and G/A links. Self-compatibility should still be attainable in a similar (50-MHz) portion of the 2200-2290 MHz band. For the case of interference to adjacent ranges, the additional transmitter power should be cancelled by the revised path loss.

EMC with Incumbent Equipment—SGLS Downlink Receivers. The Air Force Satellite Control Network (AFSCN) provides telemetry, tracking, commanding, control, and communications functions for manned and unmanned DoD and non-DoD satellite operations and other space vehicle missions. The terrestrial components of the AFSCN include operations control nodes, common-user control nodes, remote ground facilities, remote tracking stations, and automated remote tracking stations. One element of the AFSCN is the SGLS, which provides telemetry, tracking, and commanding (TT&C), as well as data and voice communications. The SGLS uplink operates between 1760-1845 MHz and the downlink operates between 2200-2290 MHz.

The SGLS downlink signal format can include any combination of ranging code and three subcarriers (carrier 1), telemetry (carrier 2), and wideband data (carrier 3). Selected downlink signal parameters relevant to this assessment are provided in Table D-23 below. Certain space vehicles may include a special S-band communications package that accommodates three carriers on a standard SGLS link. This is referred to as the M2P1 configuration and provides additional voice and data communications. For the terminals examined in this analysis, a review of the M2P1 characteristics shows the standard SGLS downlink to be more susceptible to interference than the M2P1 downlink. Consequently, the M2P1 receiver analysis is not presented here.

Table D-23. Nominal SGLS Downlink Signal Characteristics

Nominal SGLS Earth Station Parameter	Value
3 dB Bandwidth/Bit Rate	Carrier 1 1.024 MHz subcarrier PCM telemetry 7.8 bps -128 kbps 1.25 MHz subcarrier Voice 100 Hz - 3.5 kHz Analog data 100 Hz - 20 kHz 1.7 MHz subcarrier PCM/PAM telemetry 125 bps - 256 kbps PAM telemetry to 20 kHz 2.05 kHz Carrier 2 128 - 1024 kbps Carrier 3 0.2 - 10 MHz

AFSCN earth stations that receive the SGLS downlink signals are limited in number and are normally fixed facilities located at government controlled sites. A list of the fixed terminals is given in Appendix B. The fixed terminals generally include large, high gain, directional antennas. Within the control network there are smaller, transportable terminals that function as remote tracking stations and may be used for range operations and special events. These transportable terminals were the initial focus of this assessment as these terminals are the most likely to be near an uncontrolled environment, have lower link margins due to smaller antennas, and consequently may be more subject to interference.

The transportable terminals include the S-band transportable ground station (STGS), the transportable S-band terminal (TST), and the transportable space test and evaluation resource (TSTR). Of these terminals, the TST has the smallest antenna, the lower figure of merit, lowest link margin, and has the lowest interference thresholds. This analysis was performed on carrier 1 (Telemetry) and carrier 2 (1024 kbps) of the TST, using information on link margin and the resulting interference threshold taken from an earlier JSC analysis.[26] Other information was taken from the system frequency allocation application.[27] Separation distances for these terminals were expected to be representative. Relevant SGLS parameters for a number of TST functions are included in Table D-24 below.

[26] Lloyd Apirian, Ben Benedick, and Ray Dizon, *Siting Analysis Supporting Proposed AFSCN MCC Relocation to Kirtland AFB,* JSC-CR-95-015, Annapolis, MD: DoD JSC, May 1995.

[27] *Application for Equipment Frequency Allocation (DD Form 1494) for Space Ground Link Subsystem (SGLS),* J/F 12/1520/4, Washington, DC, 11 December 1967.

Table D-24. SGLS Link Budget Values

Item	TST Carrier 1			TST Carrier 2	
	Telemetry	Comm	Ranging	512 kb/s	1024 kb/s
Effective Received Power (dBm)	-110.6	-113.2	-108.1	-101.1	-101.1
Effective Noise Temperature (dBk)	22.9	22.9	22.9	22.9	22.9
N_0 (dBm/Hz)	-175.7	-175.7	-175.7	-175.7	-175.7
Bandwidth (dBHz)	45.0	43.0	60.0	57.1	60.1
E_b/N_0 (dB) C/N_0 (dB)	20.1	 22.1	 67.6	17.5	14.5
E_b/N_0 Required (dB) C/N_0 Required (dB)	9.6	 -23.0	 47	9.6	9.6
Link Margin (dB)	10.5	25.1	20.6	7.9	4.9
Required Margin (dB)	3.0	3.0	3.0	3.0	3.0
Excess Margin (dB)	7.5	22.0	17.6	4.9	1.9
N (dBm)	-130.7	-132.7	-115.7	-118.6	-115.6
I/N_{th} (dB)	6.7	8.5	17.5	3.2	-2.6
Interference threshold, I_{th}, dBm	-124.0	-110.7	-98.2	-115.4	-118.2

For the TACTS/ACMI A/G links, if no frequency coordination is assumed, a separation distance of 383 km is necessary to avoid interference to the TST downlink receiver using Carrier 1, and 392 km to avoid interference to the TST downlink receiver using Carrier 2. To avoid distance separation constraints, 5 MHz and 12 MHz separations are necessary from Carriers 1 and 2, respectively, for the situations analyzed. The SGLS downlink uses frequencies at 5 MHz intervals throughout the 2200-2290 MHz band (Reference 26).

EMC with Incumbent Equipment—Missile Telemetry Links. Various systems, such as the AN/DKT-XX series, the Aydin Vector T-series, etc. are used to telemeter the performance data of a missile weapon back to a monitoring station. A typical example is the T-802, used in the Advanced Medium Range Air-to-Air Missile (AMRAAM). This system has a transmitter with a nominal bandwidth of 2.4 MHz and an output power of about 4 watts. An omnidirectional antenna is normally used. The telemetry signals are received by range ground terminals, using receivers typified by the Defense Electronics TR-109. As these systems are generally one-way data links, there is no associated receiver on board the missile.

For telemetry use at missile test ranges, the band is divided into 89 one-MHz channels, from 2200.5 MHz to 2289.5 MHz. The missile telemetry systems are used principally on or near DoD training and weapons ranges. In some circumstances the missiles will be launched from one range and fly into an impact on another range.

At one of the major ACTS training ranges, Nellis AFB, NV, a number of frequencies throughout the 2200-2290 MHz range are assigned to specific telemetry transmitters. A large number of frequencies are assigned to the AN/DKT-37D. Information on this transmitter was obtained from the frequency allocation application[28] and frequency-distance separation criteria for avoidance of its interference to the TACTS/ACMI and JTCTS receivers were calculated. An similar analysis was performed of the effects of the TACTS/ACMI and JTCTS airborne transmitters on a typical ground-based telemetry receiver, the Microdyne Model 1100R. Information on this receiver was also taken from its frequency allocation application.[29] For each receiver, an interference threshold of 6 dB below the noise level was used.

For the TACTS/ACMI AIS transmitter interfering with the ground-based telemetry receiver, a 5 MHz frequency separation or a 392 km distance separation is needed to avoid exceeding the interference threshold. The AN/DKT-37D missile transmitter is relatively low power (2 W) and narrowband (0.5 MHz). Therefore the required separation distances and frequencies to avoid interference to the ACTS receivers are somewhat smaller compared to the ACTS-to-telemetry receiver distance. For the TACTS/ACMI AIS receiver, the minimum separation distance is 308 km, and the minimum frequency separation is 3 MHz.

Cosite Equipment at Subharmonics and Harmonics for the F/A-18 Aircraft. An assessment of the potential interference from equipment collocated with the ACTS on a typical aircraft, the F/A-18, was performed. The 2200-2290 MHz band contains second harmonics of Tactical Air Navigation/Distance Measuring Equipment (TACAN/DME) and Joint Tactical Information Distribution System (JTIDS) frequencies. Both of these equipments are located on the F/A-18 aircraft. The 2200-2290 MHz band is also a fourth subharmonic of the band occupied by the collocated AN/APN-202 beacon.

The JSC Aircraft inter-Antenna Propagation with Graphics (AAPG) computer program[30] was used to model the F/A-18 aircraft to determine the path loss between antennas on the aircraft structure. The

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[28] *Application for Equipment Frequency Allocation (DD Form 1494) for AN/DKT-37 Telemetry,* J/F 12/5971, Washington, DC, MCEB, 23 April 1985.

[29] *Application for Equipment Frequency Allocation (DD Form 1494) for Microdyne Corporation Model 1100R Receiver,* J/F 12/2702, Washington, DC, MCEB, 3 January 1969.

[30] W. Klocko, D. Katz, P. Hussar, and E. Smith-Rowland, *User Guide for AAPG 2000,* JSC-UM-98-094, Annapolis, MD: DoD JSC, March 1999.

amount of frequency-dependent rejection (FDR) was then calculated using Equation D-7, derived from Equation E-3 with L_s and L_{SP} = 0.

$$FDR = P_t + G_t + G_r - L_p - I_t \qquad \text{(D-7)}$$

where L_p is the path loss from AAPG 2000 and other quantities are as previously defined. An interference threshold 6 dB below receiver noise, which results in a loss of ten percent of communications range, was used for the ACTS systems. The value of FDR from Equation D-7, the transmitter emission spectrum, and the receiver selectivity characteristics were then input to the JSC Frequency-Dependent Rejection Calculation (FDRCAL) model to determine the amount of frequency separation necessary for the interference threshold I_t not to be exceeded.

Cosite Equipment—TACAN/DME. Use of the AAPG model resulted in a path loss of 39 dB between the TACTS fuselage-mounted antenna (on the nose wheel door) used for the internal TACTS and the lower TACAN/DME antenna, which is also used for JTIDS. Characteristics of the TACAN component of the AN/USQ-140 were used in the analysis.[31] For TACAN/DME interference to the TACTS, 63 MHz separation between the TACAN/DME harmonic and the TACTS frequency is needed for I_t not to be exceeded. For example, if the TACTS receiver operates on 2250 MHz, TACAN/DME interrogator frequencies between 1093 and 1156 MHz must be avoided. Any interrogation channels above 69 would cause the threshold to be exceeded. Channels 1-16 and 60-69, which are designated for use by the military services for tactical purposes, lie outside this range. Blanking of the TACTS receiver by the TACAN transmitter could also be investigated.

Cosite Equipment—JTIDS. To avoid JTIDS harmonic interference to TACTS, JTIDS harmonics must be separated by 31.6 MHz from the TACTS frequency. JTIDS transmitter characteristics were those of the AN/USQ-140(V) taken from the frequency allocation application (Reference 31). For example, for TACTS operation at 2250 MHz, JTIDS frequencies between 1109 and 1141 MHz need to be avoided. A loss of 10 of the 51 available JTIDS frequencies would occur. As with TACAN, blanking of the TACTS receiver when JTIDS transmits could be investigated.

Cosite Equipment—AN/APN-202. The AN/APN-202 may operate in the 8800-9500 MHz frequency range, although it often receives on 9310 MHz. A path loss of 48.5 dB was calculated using

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[31] *Application for Frequency Allocation (DD Form 1494) for Joint Tactical Information Distribution System, Multi Functional Information Distribution System (JTIDS/MIDS),* J/F 12/4413/4 (Draft).

AAPG-2000. The resulting TACTS harmonic is calculated to be -87.5 dBm. This value is 22.5 dB below the AN/APN-202 sensitivity of -65 dBm, which was used as the interference threshold. Therefore, no interference problem is expected.

Other Collocated Systems. Other collocated systems that may be affected by the reassigned TACTS AIS transmitter include the AN/ALQ-165 jammer and the AN/ALR-067 countermeasures warning and control system (CWCS). Compatibility with these systems will be assessed in the classified supplement.

Goldstone Deep Space Network and GSTDN Receivers (Ft. Irwin only). The NASA Deep Space Network (DSN) receiver at Goldstone, CA is located within the boundaries of Fort Irwin. The Air Warrior/National Training Center Integration System (AW/NTC-IS) is also located there. One of the components of the AW/NTC-IS is an ACMI. If this ACMI is moved in frequency to the 2200-2290 MHz band, the DSN receivers will have to be protected.

The primary S-band frequency range used for Deep Space spacecraft communication at Goldstone is 2290-2300 MHz, adjacent to the proposed 2200-2290 MHz band. These frequencies must be protected during sensitive events. However, the receivers are capable of operating from 2200-2300 MHz,[32] and a number of authorized frequencies of low-earth-orbit (LEO) satellites are listed in the Goldstone Authorized Frequency Database.[33] These frequencies must also be protected.

An assessment of the effects of the ACMI remote and airborne systems on the Goldstone receiver was done in a manner similar to that done in an earlier analysis.[34] For the Goldstone receivers, an interference threshold of -192 dBm/Hz and an antenna gain of 32 dBi were used. For the ACMI AIS transmitter at a 9000 km altitude, 432 km of distance separation would be needed to avoid exceeding the interference threshold. At a point 60 dB down from the maximum peak of the emission spectrum, at ±6 MHz from the carrier frequency, the minimum separation distance would be 106 km. For the ACMI TIS remote G/A link transmitter, the corresponding separation distances are 93 km and 22 km for the on-tune and -60 dB points, respectively.

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[32] Goddard Space Flight Center, *Mission Requirements and Data Systems Support Forecast,* Document 501-803, Greenbelt Maryland, August 1996, p. 7-14.

[33] "NTIA S-Band Authorized Frequencies at Goldstone," [NTIA Web page], 19 May 1999 [cited 29 November 2000]. Available from http://gts.gdscc.nasa.gov/GFACSEC/GFACFreqs.htm; INTERNET.

[34] J. Colaw, V. Casto, and G. Goodwyn, *EMC Analysis of the ASET-IV Equipment at Ft. Irwin, Hohenfels, and Ft. Chaffee (U),* ECAC-CR-91-037, Annapolis, MD: DoD ECAC, August 1991, (SECRET) (Declassify on: OADR).

Threat Simulators. A description of threat simulators operating in this band and EMC issues with a relocated TACTS/ACMI are included in the *classified* supplement to this report.

Other Incumbent Equipment. Other equipment operating in the 2200-2290 MHz band includes point-to-point microwave links at one of the training ranges, Beaufort MCAS. Of the six training ranges described in Reference 22, only one has microwave links in this band. If the TACTS/ACMI A/G and G/A links were to move to this band, compatibility with these links is expected to be an issue. It may be desirable to reassign the microwave link frequencies to a higher band.

EMC with Other Systems That May Migrate to This Band. Other systems considering migration to this band include weapons control data links. The ACTS coexisted with these systems in a similar sized piece of spectrum in the 1755-1800 MHz band. Only the A/A, A/G, and G/A links would move to the 2200-2290 MHz band, so the compatibility situation would be somewhat simpler than in the present band, if other equipment were not already in the band. However, the existence of other systems, such as the SGLS downlink receiver, missile telemetry links, and threat radar simulators, already severely limits the amount of interference-free spectrum available. The addition of weapons control data links, along with ACTS, would only add more interference possibilities to an extremely crowded band.

D.7.1.2 OPTION 4B – Move A/G and G/A Links to 4400-4940 MHz Band, and Move G/G Links to 4400-4940 or 7250-8400 MHz Band

With Option 4B, as with Option 4A, the entire 1755-1850 MHz band is no longer available for ACTS use. Instead of remaining in a reduced (50 MHz) portion of the present band, the A/G and G/A links of the TACTS/ACMI will be moved to a higher band. For relocation of a system, especially one with airborne components, a number of issues must be addressed. The two primary categories of issues include the feasibility of redesigning equipment to perform its function in the new band, and potential EMC problems with equipment already using the band. Along with the 2200-2290 MHz band, the 4400-4940 MHz band was considered as a candidate for relocation. Because it is farther in frequency from the present band, it is expected to present more redesign problems than the 2200-2290 MHz band. Although the 4400-4990 MHz band offers more spectrum than the 2200-2290 MHz band, it is also already occupied by a number of systems considered to be of prime importance to the DoD and others. As with the lower band, compatibility with other systems operating on board the platforms (aircraft or ship) where the system is installed, need to be investigated.

Major systems presently residing in the 4400-4940 MHz band include the AN/TRC-170 and AN/GRC-222 tactical line-of-sight and troposcatter radios, the US Navy Light Airborne Multipurpose System (LAMPS) and Cooperative Engagement Capability (CEC). Other systems in the band include HAVE NAP, which is used on the B-52 aircraft, the Integrated Target Control System (ITCS), which is used at the Atlantic Fleet Warfare Training Facility (AFWTF), and UAV links, such as the Pioneer UAV. As with the 2200-2290 MHz band, on aircraft and ships, interference from the harmonics of collocated Joint Tactical Information Distribution System (JTIDS) and Tactical Air Navigation (TACAN) transmitters need to be considered. In addition, the effect of harmonics of the redesigned ACTS transmitter on collocated receivers needs to be assessed. Threat simulators have also been assigned frequencies in the 4900-4990 MHz range at the NAS Oceana training range.

The effects of moving the G/G links to the 4400-4940 MHz or 7250-8400 MHz band has been treated in the previous section. For G/G links in the 4400-4940 MHz band, an additional EMC issue has been created, because all links of the ACTS systems, A/G, G/A, and A/A would have to coexist in this band.

Feasibility Assessment. To maintain the same communications range at 4.4 GHz with omnidirectional antennas, the transmitter powers would have to be increased by 7.8 dB. The TACTS/ACMI AIS transmitter would have to be increased in power from 20 to 121 watts. Devices in this power range for 2200-2290 MHz are apparently available, although not built to military specifications. Going to the higher frequency band adds an extra level of difficulty, and it is not known if transmitters at this power level can meet the power and weight constraints of fighter aircraft. It may be possible to use lower power, with the addition of a high-gain antenna with tracking capabilities at the ground station. The feasibility of this arrangement and the ability to track maneuvering aircraft would need to be determined.

Self-Compatibility. In the analysis for the 1755-1850 MHz band, self-compatibility within this band segment was predicted for the TACTS/ACMI A/G and G/A links. Self-compatibility for these links should still be attainable in a similar (50-MHz) portion of the 4400-4940 MHz band. For the case of interference to adjacent ranges, the additional transmitter power needed should be cancelled by the revised path loss. If the G/G links were also to be in this band, more than 72 MHz would be needed, as was the case for 1755-1850 MHz band.

EMC with Incumbent Equipment—AN/TRC-170/AN/GRC-222. Frequency and distance separations necessary to avoid interference from the TACTS/ACMI AIS transmitter to the AN/TRC-170 receiver in the line-of-sight (LOS) and troposcatter configurations were calculated using characteristics and thresholds from an earlier analysis.[35] For the LOS mode, an interference threshold of -76 dBm, corresponding to a reliability of 99.99% for a link length of 20 km, was used. For the troposcatter mode, a threshold of -100 dBm, corresponding to 99.99% reliabiliity for a link length of 100 km, was used. Thresholds were determined from Figures 1 and 2 of Reference 35. Calculations for the AN/TRC-170 mainbeam (44 dBi), near-sidelobe (10 dBi) and backlobe (0 dBi) gains were made. Results are given in Table D-25. Distance separations in Table D-25 assume no off-tuning, and frequency separations assume a 1 km separation distance. Values in parentheses are for the power raised by the amount to achieve the same communications range at 4600 MHz as at 1800 MHz.

Table D-25. Distance and Frequency Separations Necessary to Avoid Interference From TACTS/ACMI AIS Transmitter to AN/TRC-170 Receivers

Mode	AN/TRC-170 Gain, dBi	Distance, Km	Frequency, MHz
LOS	0	0	0
	10	8	2
	44	386	6
Troposcatter	0	60 (155)	4 (4.7)
	10	192 (384)	5 (5.9)
	44	404 (410)	12.7 (19.1)

From Table D-25 it can be seen that a reasonable amount of frequency separation between TACTS/ACMI and AN/TRC-170 equipment should be observed, especially when the TACTS/ACMI aircraft may fly through the mainbeam of the AN/TRC-170 transmitter antenna.

EMC with Incumbent Equipment—Pioneer UAV. The Pioneer unmanned aerial vehicle (UAV) has RF links at UHF and C band. There is a primary C band link at 4 GHz and an alternate link at 5 GHz. The 4430-4590 MHz frequency range supports the primary uplink and 4750-4950 MHz supports the downlink. The downlink data may be video, infrared sensor information, or telemetry data, and the uplink is command data. In CONUS, use of the Pioneer UAV generally occurs at the test ranges of the Southwest or at sea. Pioneer flights take place on an intermittent basis. Two methods of addressing compatibility issues with Pioneer are coordinating times of Pioneer flights with ACTS training missions, and using the alternate (5 GHz) link.

EMC with Incumbent Equipment—AGM-142 (HAVE NAP). The AGM-142 missile is operational on B-52 aircraft. Training missions for this missile can occur anywhere over the US, but generally in

[35] Suresh Agarwal, *Analysis of the AN/TRC-170 When Deployed As Part of the Tactical Air Control System*, ECAC-PR-78-071, Annapolis, MD, DoD ECAC, December 1978.

Western regions. Live launches usually occur at White Sands Missile Range and at the Utah Test and Training Range. Maintenance and checkout is usually performed at Barksdale AFB, LA. Specific frequency ranges and other characteristics of this system are classified. The AGM-142 will not be addressed further in this study.

EMC with Incumbent Equipment—LAMPS. Compatibility issues with LAMPS are described in the *classified* supplement.

EMC with Incumbent Equipment—CEC. CEC is a system that provides the means to conduct coordinated Anti-Air Warfare (AAW) area defense. All Cooperating Units (CU) that participate in a CEC network exchange sensor data in near real time to form an identical composite track and identification air surveillance picture on each CU. This sensor cooperation function allows targets to be detected and compositely tracked that a single individual sensor could not track. The composite air picture provides the means for a battle force to accomplish optimized weapon system assignments and the coordinated engagements of threats. CEC is implemented via a Cooperative Engagement Processor (CEP) and a Data Distribution System (DDS). The CEP is a computer system responsible for forming the composite track and identification data base, and for coordinating engagements. The DDS is an RF network responsible for the secure, environmentally resistant transfer of sensor and weapon data among the CUs. CEC is currently being deployed aboard Navy E-2C aircraft and the major Navy surface combatants, carriers, and amphibious class ships. CEC is also now in development for deployment with the USA PATRIOT, USAF Airborne Warning and Control System (AWACS), and USMC AN/SPS-59 radar systems. The parameters for CEC are provided in Table C-30.

EMC with Incumbent Equipment—Threat Simulators. Threat simulators in the 4900-4990 MHz frequency range have been assigned frequencies at the NAS Oceana training range (Reference 22). This band overlaps part of the 4400-4940 MHz band. At Oceana, and at other ranges that may use threat simulators in this band, assignment of ACTS frequencies in the 4900-4940 MHz range should be avoided. A list of threat radars in the 4400-4940 MHz band is given in the *classified* supplement.

Cosite Equipment at Subharmonics and Harmonics for the F/A-18 Aircraft. An assessment of the potential interference from equipment collocated with the ACTS on a typical aircraft, the F/A-18, was performed. The 4400-4940 MHz band contains fourth harmonics of Tactical Air Navigation/Distance Measuring Equipment (TACAN/DME) and Joint Tactical Information Distribution System (JTIDS) frequencies. Both of these equipments are located on the F/A-18 aircraft. The 4400-4940 MHz band is also a second subharmonic of the band occupied by the collocated AN/APN-202 beacon and AN/APG-65/73 fire control radar.

As was done for the 2200-2290 MHz band, the JSC Aircraft inter-Antenna Propagation with Graphics (AAPG) computer program was used to model the F/A-18 aircraft to determine the path loss between antennas on the aircraft structure. An analysis to determine the frequency constraints on the fundamental emitter to avoid potential interference from its harmonic was then performed.

Cosite Equipment—TACAN/DME. Use of the AAPG model resulted in a path loss of 45 dB between the TACTS fuselage-mounted antenna (on the nose wheel door) used for the internal TACTS and the lower TACAN/DME antenna, which is also used for JTIDS. For TACAN/DME interference to the TACTS, 31.6 MHz separation between the TACAN/DME harmonic and the TACTS frequency is needed for I_t not to be exceeded. For example, if the TACTS receiver operates on 4600 MHz, TACAN/DME interrogator frequencies above 1142 MHz must be avoided. Any interrogation channels above 118 would cause the threshold to be exceeded.

Cosite Equipment—JTIDS. To avoid JTIDS harmonic interference to TACTS, JTIDS harmonics must be separated by 8.8 MHz from the TACTS frequency. A rejection value of 80 dB was assumed for the fourth harmonic (Reference 31). For example, for TACTS operation at 4600 MHz, JTIDS frequencies between 1148 and 1152 MHz need to be avoided. A loss of two of the 51 available JTIDS frequencies would occur.

Cosite Equipment—AN/APN-202. The TACTS, in the 4400-4940 MHz band, lies at the second subharmonic of the AN/APN-202 beacon frequency range. The TACTS second harmonic is calculated to be -87.5 dBm, 22.5 dB lower than the AN/APN-202 sensitivity of -65 dBm. Interference to the AN/APN-202 is not expected.

Cosite Equipment—Fire Control Radar. The TACTS, in the 4400-4940 MHz band, lies at the second subharmonic of the AN/APG-65/73 radar tuning range. An assessment of interference to the radar is included in the classified supplement.

Cosite Equipment—AN/APN-194 Radar Altimeter. The AN/APN-194 Doppler radar altimeter operates at a center frequency of 4300 MHz. At least 61 dB rejection of the TACTS AIS signal is necessary for the signal to be below the -85 dBm sensitivity level of the AN/APN-194. This rejection should be attainable at a frequency separation of less than 100 MHz. At least 101 dB of rejection is needed for the AN/APN-194 signal peak power to be below the TACTS AIS interference threshold. If this amount of FDR is not attainable, because of the low duty cycle of the altimeter, (.00072), blanking of the TACTS receiver may be a feasible mitigation technique.

Other Collocated Systems. Other collocated systems that may be affected by the reassigned TACTS AIS transmitter include the AN/ALQ-165 jammer and the AN/ALR-067 CWCS. Compatibility with these systems will be assessed in the classified supplement.

Compatibility with Other Systems Migrating to This Band. The 4400-4940 MHz band contains more spectrum (540 MHz) compared to the lower bands, so compatibility with the additional equipment, such as weapons control data links, that may migrate to the 4400-4940 MHz band would be more readily achieved than at the lower bands. This situation would occur even if the G/G links were moved to the band. However, the presence of the systems already in the band may negate most of the advantage given by the wider bandwidth.

D.7.2 JTCTS A/A and G/A Links Technical Assessment

D.7.2.1 OPTION 4A – Move G/A and A/A Links to 2200-2290 MHz Band, and Move G/G Links to 4400-4940 or 7250-8400 MHz Band

With Option 4A, the entire 1755-1850 MHz band is no longer available for ACTS use. Instead of remaining in a reduced (50 MHz) portion of the present band, the G/A and A/A links of the JTCTS will be moved to a higher band. Two candidate bands were considered for this study. They are the 2200-2290 MHz and 4400-4940 MHz bands. For relocation of a system, especially one with airborne components, a number of issues must be addressed. The two primary categories of issues include the feasibility of redesigning equipment to perform its function in the new band, and potential EMC problems with equipment already using the band. The 2200-2290 MHz band was considered as a prime candidate for relocation. Because it is closest in frequency to the present band, it is expected to present a minimum number of redesign problems. However, it is already occupied by a number of systems considered to be of prime importance to the DoD and others. In addition, compatibility with other systems operating on board the platforms (aircraft or ship) where the system is installed, need to be investigated.

Systems presently residing in the 2200-2290 MHz band include Space Ground Link Subsystem (SGLS) downlink receivers, missile telemetry links, threat simulators, and the NASA Goldstone Deep Space Network (DSN) and Space Tracking and Data Network (STDN) receivers located near one of the training ranges, at Fort Irwin, CA. At the Beaufort MCAS, eight microwave links are assigned frequencies from 2208 to 2285 MHz. On aircraft and ships, interference from the harmonics of collocated Joint Tactical Information Distribution System (JTIDS) and Tactical Air Navigation

(TACAN) transmitters need to be considered. In addition, the effect of harmonics of the redesigned ACTS transmitter on collocated receivers needs to be assessed.

The effects of moving the G/G links to the 4400-4940 MHz or 7250-8400 MHz band has been treated in the previous section. For the 4400-4940 MHz band, an additional EMC issue has been created, because harmonics of transmitters in the 2200-2290 MHz band lie within this frequency range.

Feasibility Assessment. As was the case for the TACTS/ACMI, the JTCTS transmitter powers would have to be increased by 1.9 dB, or, in the case of JTCTS, to 105 watts. According to JTCTS program consultants (Reference 24), high power devices for this band are available, but they do not meet military specifications for packaging or temperature range. Although individual parts may need to be screened, implementation is believed to be feasible.

Self-Compatibility. In the analysis for the 1755-1805 MHz band, it was found that compatibility within the same range could be attained at a 20-km distance between G/A and A/A links, if the frequency separation between the two links was 35 MHz or more. Compatibility could therefore be attained in a 58-MHz portion of the 2200-2290 MHz band. Compatibility between links of adjacent ranges requires an additional 22.8 MHz for each link. Adding the additional 45.6 MHz to the 58 MHz needed for compatibility within the same range results in 103.6 MHz, greater than 90 MHz. Therefore, even if compatibility with other systems within the band were of no concern, compatibility between adjacent ranges cannot be achieved by frequency separation alone in the 2200-2290 MHz band.

EMC with Incumbent Equipment—SGLS Downlink Receivers. An analysis of interference from the JTCTS air-to-air link to the SGLS downlink receivers was conducted in a manner similar to that described for the TACTS/ACMI air-to-ground link transmitter. For TST Carrier 1, a 392 km distance separation is needed for no frequency separation constraints, and for TST Carrier 2, 402 km separation is needed. The frequency separation constraints are somewhat larger than for the TACTS/ACMI, because of the wider bandwidth of the JTCTS. For Carrier 1, 27 MHz separation is needed at minimal distance, and for Carrier 2, 37 MHz separation is needed.

EMC with Incumbent Equipment—Missile Telemetry Links. An analysis for required frequency and distance separations between the JTCTS airborne transmitter and a ground-based telemetry receiver, the Microdyne 1100R, and between the AN/DKT-37 missile telemetry transmitter and the JTCTS airborne receiver was conducted, using methodology similar to that used for the TACTS/ACMI equipment described above.

For the JTCTS A/A transmitter interfering with the ground-based telemetry receiver, a 35-MHz frequency separation or a 401 km distance separation is needed to avoid exceeding the interference threshold. The larger frequency separation and separation distance for the JTCTS, as compared to the TACTS/ACMI, are due to its broader bandwidth and higher power level. The JTCTS high power and wideband modes were assumed for this analysis. To avoid the missile telemetry transmitter signal exceeding the interference threshold of the JTCTS airborne receiver, a distance separation of 117 km or a frequency separation of 27 MHz must be maintained.

Cosite Equipment at Subharmonics and Harmonics for the F/A-18 Aircraft. An investigation of JTCTS transceiver interference effects from and to collocated transmitters and receivers on the F/A-18 aircraft was performed in the same manner as described for the TACTS/ACMI. The results are discussed below.

Cosite Equipment—TACAN/DME. To avoid TACAN/DME interference to JTCTS, about 100 MHz of frequency separation would be needed. The increased frequency separation, compared to TACTS, is largely due to the wider bandwidth of the JTCTS receiver. All TACAN/DME channels above 50 would cause harmonics above the threshold level. The military-only channels 1-16 would continue to generate harmonics below the interference threshold.

Cosite Equipment—JTIDS. To avoid JTIDS harmonic interference to JTCTS, about 63 MHz frequency separation is needed. JTIDS frequencies between 1093 and 1157 MHz would cause the interference threshold to be exceeded for the hypothetical situation of JTCTS operating at 2250 MHz. Of the 51 JTIDS frequencies, 21 would exceed the interference threshold.

Cosite Equipment—AN/APN-202. The second harmonic of the JTCTS at the AN/APN-202 receiver input is calculated to be -71.2 dBm, lower than the -65 dBm sensitivity of the AN/APN-202 receiver. Interference to the AN/APN-202 from JTCTS in the 2200-2290 MHz band is not expected to be a problem.

Other Collocated Systems. Other collocated systems that may be affected by the reassigned JTCTS airborne transmitter include the AN/ALQ-165 jammer and the AN/ALR-067 CWCS. Compatibility with these systems will be assessed in the classified supplement.

Collocated Shipboard Systems. The JTCTS, when used for exercises at sea, is expected to have a transmitter and possibly a receiver on board ship. Compatibility of these systems with other shipboard equipment would need to be assessed.

<u>Goldstone Deep Space Network and GSTDN Receivers (Ft. Irwin only)</u>. An assessment of the effects of the JTCTS airborne transmitter on the Goldstone receiver was done in a manner similar to that described above for the ACMI systems. At a 9000 m altitude, 439 km of separation is needed to avoid exceeding the interference threshold with no offtuning, and 309 km separation is needed at the -60 dB spectral level, ± 11.25 MHz.

<u>Threat Simulators</u>. A description of threat simulators operating in this band and EMC issues with a relocated JTCTS are included in the *classified* supplement to this report.

<u>Other Incumbent Equipment</u>*.* Other equipment operating in the 2200-2290 MHz band includes point-to-point microwave links at one of the training ranges, Beaufort MCAS. Of the six training ranges described in Reference 22, only one has microwave links in this band. If the JTCTS A/A and G/A links were to move to this band, compatibility with these links is expected to be an issue. It may be desirable to reassign the microwave link frequencies to a higher band.

<u>EMC with Other Systems That May Migrate to This Band</u>. As with the TACTS/ACMI, addition of weapons control data links, or other systems, to this band due to overall reduction of spectrum available to DoD only adds more interference possibilities to an already overcrowded band.

D.7.2.2 OPTION 4B – Move G/A and A/A Links to 4400-4940 MHz Band, and Move G/G Links to 4400-4940 or 7250-8400 MHz Band

With Option 4B, as with Option 4A, the entire 1755-1850 MHz band is no longer available for ACTS use. Instead of remaining in a reduced (50 MHz) portion of the present band, G/A and A/A links of the JTCTS will be moved to a higher band. For relocation of a system, especially one with airborne components, a number of issues must be addressed. These issues for the JTCTS are much the same as for the TACTS/ACMI, described earlier. The two primary categories of issues include the feasibility of redesigning equipment to perform its function in the new band, and potential EMC problems with equipment already using the band. Because the 4400-4940 MHz band is farther in frequency from the present band, it is expected to present more redesign problems than the 2200-2290 MHz band. Although the 4400-4990 MHz band offers more spectrum than the 2200-2290 MHz band, it is also already occupied by a number of systems considered to be of prime importance to the DoD and others. As with the lower band, compatibility with other systems operating on board the platforms (aircraft or ship) where the system is installed, need to be investigated.

Major systems presently residing in the 4400-4940 MHz band have been listed in the TACTS/ACMI discussion, and will be repeated here for convenience. They include the AN/TRC-170 and AN/GRC-222 tactical line-of-sight and troposcatter radios, the US Navy Light Airborne Multipurpose System (LAMPS) and Cooperative Engagement Capability (CEC). Other systems in the band include HAVE NAP, which is used on the B-52 aircraft, the Integrated Target Control System (ITCS), which is used at the Atlantic Fleet Warfare Training Facility (AFWTF), and UAV links, such as the Pioneer UAV. As with the 2200-2290 MHz band, on aircraft and ships, interference from the harmonics of collocated Joint Tactical Information Distribution System (JTIDS) and Tactical Air Navigation (TACAN) transmitters need to be considered. In addition, the effect of harmonics of the redesigned ACTS transmitter on collocated receivers needs to be assessed. Threat simulators have also been assigned frequencies in the 4900-4990 MHz range at the NAS Oceana training range.

The effects of moving the G/G links to the 4400-4940 MHz or 7250-8400 MHz band has been treated in the previous sections. For G/G links in the 4400-4940 MHz band, an additional EMC issue has been created, because all links of the ACTS systems, A/G, G/A, and A/A would have to coexist in this band.

Feasibility Assessment. To operate without reduced communications range in the 4400-4940 MHz band, the JTCTS transmitter would have to be increased in power to 400 watts. According to JTCTS program consultants (Reference 24), for aircraft using the pod version of the JTCTS, the prime power available at the wing station is not sufficient to provide this amount of transmitter power. Operating the JTCTS at this frequency band with omnidirectional antennas, as is necessary for the air-to-air link, may not be feasible.

Self-Compatibility. According to analyses referred to for the 2200-2290 MHz band, 103 MHz was predicted to be necessary for compatibility of both G/A and A/A links in the same range and adjacent ranges. Although this amount of spectrum was not available in the lower bands, it should be available, barring interference problems with incumbent systems, in the 4400-4940 MHz band. If compatibility with incumbent systems can be managed, the available spectrum should be able to include the tertiary (G/G) link as well.

EMC with Incumbent Equipment—AN/TRC-170/AN/GRC-222. Frequency and distance separations necessary to avoid interference from the JTCTS airborne transmitter to the AN/TRC-170 receiver in the line-of-sight (LOS) and troposcatter configurations were calculated using the methods described for the TACTS/ACMI analysis. The results are given in Table D-26. Frequency separations to be observed are somewhat larger than for the TACTS/ACMI AIS. Frequency separations of up to 20 MHz should be observed, even if the mainbeam of the AN/TRC-170 is avoided. In Table D-26, numbers in parentheses are for the JTCTS transmitter power raised to meet the same communications range as at 1800 MHz.

Table D-26. Distance and Frequency Separations Necessary to Avoid Interference From JTCTS Airborne Transmitter to AN/TRC-170 Receivers

Mode	AN/TRC-170 Gain, dBi	Distance, Km	Frequency, MHz
LOS	0	5	2.2
	10	33 (86)	6 (11.2)
	44	393	29
Troposcatter	0	171 (383)	14 (18.9)
	10	385 (391)	20 (26.5)
	44	411 (416)	67 (69)

EMC with Incumbent Equipment—LAMPS. Compatibility issues with LAMPS are described in the *classified* supplement.

EMC with Incumbent Equipment—CEC. Compatibility issues between the JTCTS and the CEC are described in the *classified* supplement.

EMC with Incumbent Equipment—Threat Simulators. As mentioned earlier,threat simulators in the 4900-4990 MHz frequency range have been assigned frequencies at the NAS Oceana training range (Reference 22). This band overlaps part of the 4400-4940 MHz band. At Oceana, and at other ranges that may use threat simulators in this band, assignment of ACTS frequencies in the 4900-4940 MHz range should be avoided. A list of threat radars in the 4400-4940 MHz band is given in the classified supplement.

Cosite Equipment at Subharmonics and Harmonics for the F/A-18 Aircraft. An investigation of JTCTS transceiver interference effects from and to collocated transmitters and receivers on the F/A-18 aircraft was performed in the same manner as described for the TACTS/ACMI. The results are discussed below.

Cosite Equipment—TACAN/DME. To avoid TACAN/DME interference to JTCTS, about 54.5 MHz of frequency separation would be needed. The increased frequency separation, compared to TACTS, is largely due to the wider bandwidth of the JTCTS receiver. For JTCTS operation at mid-band (4600 MHz), all TACAN/DME channels above 112 would cause harmonics above the threshold level.

Cosite Equipment—JTIDS. To avoid JTIDS harmonic interference to JTCTS, 27.4 MHz of frequency separation is needed. JTIDS frequencies between 1143 and 1157 MHz would cause the interference threshold to be exceeded for the hypothetical situation of JTCTS operating at 4600 MHz. Of the 51 JTIDS frequencies, five would exceed the interference threshold.

Cosite Equipment—AN/APN-202. The JTCTS, in the 4400-4940 MHz band, lies at the second subharmonic of the AN/APN-202 beacon frequency range. The JTCTS second harmonic is calculated to be -71.2 dBm, 6.2 dB lower than the AN/APN-202 sensitivity of -65 dBm. Interference to the AN/APN-202 is not expected.

Cosite Equipment—Fire Control Radar. The JTCTS, in the 4400-4940 MHz band, lies at the second subharmonic of the AN/APG-65/73 radar tuning range. An assessment of interference to the radar is included in the classified supplement.

Cosite Equipment—AN/APN-194 Radar Altimeter. The AN/APN-194 Doppler radar altimeter operates at a center frequency of 4300 MHz. At least 72 dB rejection of the JTCTS signal is necessary for the signal to be below the -85 dBm sensitivity level of the AN/APN-194. This rejection should be attainable at a frequency separation of less than 100 MHz. At least 98 dB of rejection is needed for the AN/APN-194 signal peak power to be below the JTCTS interference threshold. If this amount of rejection is not attainable through frequency separation, the low duty cycle of the altimeter, (.00072), may allow blanking of the JTCTS receiver as a feasible mitigation technique.

Other Collocated Systems. Other collocated systems that may be affected by the reassigned JTCTS airborne transmitter include the AN/ALQ-165 jammer and the AN/ALR-067 CWCS. Compatibility with these systems will be assessed in the classified supplement

Compatibility with Other Systems Migrating to This Band. The same situation applies to the JTCTS as to TACTS/ACMI. As this band contains more spectrum (540 MHz) compared to the lower bands, compatibility with the additional equipment, such as weapons control data links, in the band would be more readily achieved than at the lower bands. This situation would occur even if the G/G links were moved to the band. However, the presence of the systems already in the band may negate most of the advantage given by the wider bandwidth. Since the JTCTS uses more transmitter power and receiver bandwidth, compatibility appears to be more difficult to achieve than is the case with TACTS/ACMI.

D.7.3 Results – Option 4

1. It is generally feasible to redesign the TACTS/ACMI or JTCTS airborne transmitters to attain the present system ranges at 2200-2290 MHz.
2. A number of systems operating in the 2200-2290 MHz band would present compatibility problems and possibly operational constraints. They include:
   a. Missile telemetry links, at Nellis AFB and elsewhere
   b. SGLS fixed and transportable S-band downlink terminals
   c. NASA Goldstone DSN and GSTDN receivers, at Fort Irwin, CA
   d. Threat radar simulators (see classified supplement)
   e. Point-to-point microwave links (Beaufort MCAS)
3. Use of the redesigned system at 2200-2290 MHz on a typical fighter aircraft presents potential cosite EMC problems with other systems on that aircraft. These systems include:
   a. TACAN/DME interrogators
   b. JTIDS
   c. Jammers
   d. Radar Warning Receivers
4. It is probably not feasible to redesign the JTCTS transmitter to operate in the 4400-4940 MHz band with a 150-nmi range to be installed on present-day fighter aircraft.
5. The number of systems already operating in the 4400-4940 MHz band is somewhat smaller than at 2200-2290 MHz. These systems include:
   a. Tactical point-to-point and troposcatter radios
   b. Unmanned aerial vehicles
   c. Cooperative Engagement Capability (CEC) (See classified supplement)
   d. Threat simulators (See classified supplement)
6. The CEC is expected to be the primary contender for spectrum in this band.
7. As with the 2200-2290 MHz band, use of the redesigned system on a fighter aircraft, if feasible, presents a number of cosite interference problems, similar to the ones mentioned for 2200-2290 MHz.
8. EMC issues with G/G links, migrating to the 4400-4940 MHz or 7250-8400 MHz band, are expected to be tractable, as was the case for Option 3.

D.7.4 Operational Impact

One option presented by the Air Force is to upgrade all ACTS ranges and AIS pods with a GPS tracking capability and replace existing RF hardware with new, state of the art, digital equipment. AIS pod uplink and downlink frequencies could also be moved to the 2200-2290 MHz band. Use of GPS for position determination will reduce the bandwidth of the uplinks and downlinks, from greater than 7 MHz to less than 1.2 MHz and also eliminate the use of multiple frequency assignments for ground-to-ground communications resulting in reduced total bandwidth required for ACTS ranges. Moving the TACTS/ACMI to a different band could not be implemented by 2003 or likely by 2006. Therefore, vacating the current band in those time frames would impose unacceptable impact to combat training. One of the above options for moving to an alternate frequency band could possibly be implemented by 2010. However, unless continued operation of legacy TACTS/ACMI is assured in the interim, operational impacts would be severe.

By 2003, JTCTS will not yet be deployed in the US and it would be difficult to make any significant modifications to the legacy TACTS/ACMI.Operational impact to US forces is the same as in Option 1. In 2010,the replacement of the legacy TACTS/ACMI by JTCTS will have just begun (2008).The 2010 time frame may allow for an accelerated JTCTS program to provide replacement TACTS/ACMI. A modification program for the legacy TACTS/ACMI could also be completed by that time frame—but that would be moot if all systems have been replaced by JTCTS. Operational impact is none if no spectrum conflicts arises with other systems and all the mitigation efforts are completely implemented by 2010 or if turnover of 1755-1850 MHz can be delayed at sites where mitigation measures have not been completed by 2010. Compatibility issues with incumbent systems in the 2200-2290 and 4400-4940 MHz frequency bands may prevent the implementation of this option.